PB82-184722

Compilation of Air Pollutant Emission Factors
Third Edition, (Including Supplements 1-7)
Supplement Number 12

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Apr 81

U.S. Department of Commerce
National Technical Information Service
NTIS

PB82-184722

AP-42
Supplement 12

SUPPLEMENT NO. 12
FOR

COMPILATION OF AIR POLLUTANT EMISSION FACTORS, THIRD EDITION (INCLUDING SUPPLEMENTS 1-7)

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

April 1981

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. AP-42, Supplement 12	2.	3. RECIPIENT'S ACCESSION NO. PB82 184722
4. TITLE AND SUBTITLE Supplement 12 for Compilation of Air Pollutant Emission Factors, AP-42		5. REPORT DATE April 1981 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Monitoring and Data Analysis Division		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Environmental Protection Agency Office of Air, Noise and Radiation Office of Air Quality Planning and Standards Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same as box 9.		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

EPA Editor: Whitmel M. Joyner

16. ABSTRACT

In this Supplement for AP-42, revised or updated emissions data are presented for Dry Cleaning; Surface Coating; Storage of Organic Liquids; Solvent Degreasing; Graphic Arts; Consumer/commercial Solvent Use; Sulfuric Acid; Beer Making; Ammonium Sulfate; Primary Aluminum; Secondary Aluminum; Gray Iron Foundries; Steel Foundries; Secondary Zinc; Asphaltic Concrete; Asphalt Roofing; NEDS Source Classification Codes and Emission Factor Listing; and Table of Lead Emission Factors.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Fuel Combustion Emissions Emission Factors Stationary Sources Lead Emissions Source Classification Codes		

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* 20. SECURITY CLASS *(This page)*	21. NO. OF PAGES 22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

INSTRUCTIONS FOR INSERTING SUPPLEMENT 12

into AP-42

Pages iii through v replace same. New Contents.

Pages vii and viii replace same. New Publications in Series.

Pages 4.1-1 through 4.1-6 replace 4.1-1 through 4.1-4. Major Revision.

Page 4.2-1 and pp. 4.2.1-1 through 4.2.2-31 replace 4.2-1 and 4.2-2. Major Revision.

Pages 4.3-1 through 4.3-25 replace 4.3-1 through 4.3-17. Major Revision.

Pages 4.6-1 through 4.6-7 replace 4.6-1 through 4.6-5. Major Revision.

Add pages 4.9-1 through 4.9-12 and pp. 4.9.2-1 through 4.9.2-6. New Section and Subsection.

Add pages 4.10-1 through 4.10-3. New Section.

Pages 5.17-1 through 5.17-9 replace 5.17-1 through 5.17-8. Major Revision.

Pages 6.5-1 and 6.5-2 replace same. Editorial Changes.

Add pages 6.5.1-1 through 6.5.1-4. New Subsection.

Add pages 6.18-1 through 6.18-4. New Section.

Pages 7.1-1 through 7.1-9 replace 7.1-1 through 7.1-8. Major Revision.

Pages 7.8-1 through 7.8-7 replace 7.8-1 and 7.8-2. Major Revision.

Pages 7.10-1 through 7.10-9 replace 7.10-1 and 7.10-2. Major Revision.

Pages 7.11-7 and 7.11-8 replace same. Editorial Changes.

Pages 7.13-1 through 7.13-6 replace 7.13-1 and 7.13-2. Major Revision.

Pages 7.14-1 through 7.14-8 replace 7.14-1 and 7.14-2. Major Revision.

Page 8.0-1 and pp. 8.1-1 through 8.1-13 replace 8.1-1 through 8.1-5. Major Revision.

Pages 8.2-1 through 8.2-8 replace 8.2-1 through 8.2-6. Major Revision.

Page C-1 replaces C-1 through C-77. Special Notice.

Pages E-1 through E-4 and page E-9 replace same. Minor Revision.

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4. EVAPORATION LOSS SOURCES

Evaporation losses include the organic solvents emitted from dry cleaning plants and surface coating operations, and the volatile matter in petroleum products. This chapter presents the volatile organic emissions from these sources, including liquid petroleum storage and marketing. Where possible, the effect is shown of controls to reduce the emissions of organic compounds.

4.1 DRY CLEANING

4.1.1 General[1,2]

Dry cleaning involves the cleaning of fabrics with nonaqueous organic solvents. The dry cleaning process requires three steps: (1) washing the fabric in solvent, (2) spinning to extract excess solvent and (3) drying by tumbling in a hot air stream.

Two general types of cleaning fluids are used in the industry, petroleum solvents and synthetic solvents. Petroleum solvents, such as Stoddard or 140-F, are inexpensive combustible hydrocarbon mixtures similar to kerosene. Operations using petroleum solvents are known as petroleum plants. Synthetic solvents are nonflammable but more expensive halogenated hydrocarbons. Perchloroethylene and trichlorotrifluoroethane are the two synthetic dry cleaning solvents presently in use. Operations using these synthetic solvents are respectively called "perc" plants and fluorocarbon plants.

There are two basic types of dry cleaning machines, transfer and dry-to-dry. Transfer machines accomplish washing and drying in separate machines. Usually, the washer extracts excess solvent from the clothes before they are transferred to the dryer, but some older petroleum plants have separate extractors for this purpose. Dry-to-dry machines are single units that perform all of the washing, extraction and drying operations. All petroleum solvent machines are the transfer type, but synthetic solvent plants can be either type.

The dry cleaning industry can be divided into three sectors, coin operated facilities, commercial operations and industrial cleaners. Coin operated facilities are usually part of a laundry supplying "self-service" dry cleaning for consumers. Only synthetic solvents are used in coin operated dry cleaning machines. Such machines are small, with a capacity of 3.6 to 11.5 kg (8 to 25 lb) of clothing.

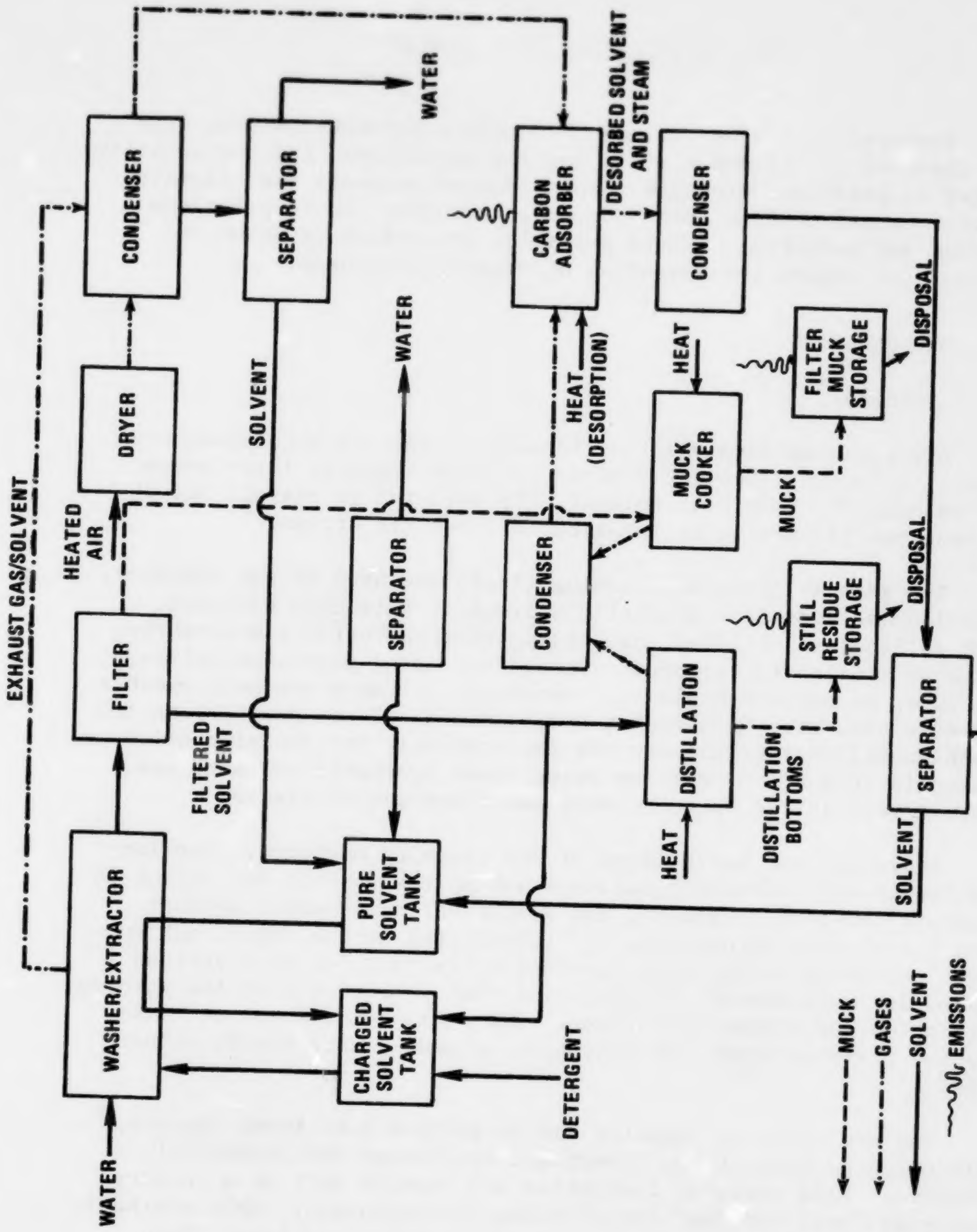
WATER
WASHER/EXTRACTOR
CHARGED SOLVENT TANK
DETERGENT
PURE SOLVENT TANK
EXHAUST GAS/SOLVENT
FILTER
FILTERED SOLVENT
HEATED AIR
DRYER
CONDENSER
SEPARATOR
WATER
SOLVENT
SEPARATOR
WATER
CONDENSER
CARBON ADSORBER
HEAT (DESORPTION)
DESORBED SOLVENT AND STEAM
CONDENSER
DISTILLATION
HEAT
DISTILLATION BOTTOMS
MUCK COOKER
HEAT
MUCK
FILTER MUCK STORAGE
DISPOSAL
STILL RESIDUE STORAGE
DISPOSAL
SEPARATOR
SOLVENT
WATER
MUCK
GASES
SOLVENT
EMISSIONS

Figure 4.1-1. Perchloroethylene dry cleaning plant flow diagram.

Commercial operations, such as small neighborhood or franchise dry cleaning shops, clean soiled apparel for the consumer. Generally, perchloroethylene and petroleum solvents are used in commercial operations. A typical "perc" plant operates a 14 to 27 kg (30 to 60 lb) capacity washer/extractor and an equivalent size reclaiming dryer.

Industrial cleaners are larger dry cleaning plants which supply rental service of uniforms, mats, mops, etc., to businesses or industries. Perchloroethylene is used by approximately 50 percent of the industrial dry cleaning establishments. A typical large industrial cleaner has a 230 kg (500 lb) capacity washer/extractor and three to six 38 kg (100 lb) capacity dryers.

A typical perc plant is shown in Figure 4.1-1. Although one solvent tank may be used, the typical perc plant uses two tanks for washing. One tank contains pure solvent, and the other contains "charged" solvent (used solvent to which small amounts of detergent have been added to aid in cleaning). Generally, clothes are cleaned in charged solvent and rinsed in pure solvent. A water bath may also be used.

After the clothes have been washed, the used solvent is filtered, and part of the filtered solvent is returned to the charged solvent tank for washing the next load. The remaining solvent is then distilled to remove oils, fats, greases, etc., and is returned to the pure solvent tank. The resulting distillation bottoms are typically stored on the premises until disposed of. The filter cake and collected solids (muck) are usually removed from the filter once a day. Before disposal, the muck may be "cooked" to recover additional solvent. Still and muck cooker vapors are vented to a condenser and separator, where more solvent is reclaimed. In many perc plants, the condenser offgases are vented to a carbon adsorption unit for additional solvent recovery.

After washing, the clothes are transferred to the dryer to be tumbled in a heated air stream. Exhaust gases from the dryer, along with a small amount of exhaust gases from the washer/extractor, are vented to a water cooled condenser and water separator. Recovered solvent is returned to the pure solvent storage tank. In 30 to 50 percent of the perc plants, the condenser offgases are vented to a carbon adsorption unit for additional solvent recovery. To reclaim this solvent, the unit must be periodically desorbed with steam, usually at the end of each day. Desorbed solvent and water are condensed and separated, and recovered solvent is returned to the pure solvent tank.

A petroleum plant would differ from Figure 4.1-1 chiefly in that there would be no recovery of solvent from the washer and dryer and no muck cooker. A fluorocarbon plant would differ in that an unvented refrigeration system would be used in place of a carbon adsorption unit. Another difference is that a typical fluorocarbon plant could use a cartridge filter which is drained and disposed of after several hundred cycles.

Emissions and Controls[1-3]

The solvent itself is the primary emission from dry cleaning operations. Solvent is given off by washer, dryer, solvent still, muck cooker, still residue and filter muck storage areas, as well as by leaky pipes, flanges and pumps.

Petroleum plants have not generally employed solvent recovery, because of the low cost of petroleum solvents and the fire hazards associated with collecting vapors. Some emission control, however, can be obtained by maintaining all equipment (e.g., preventing lint accumulation, solvent leakage, etc.) and by using good operating practices (e.g., not overloading machinery). Both carbon adsorption and incineration appear to be technically feasible controls for petroleum plants, but costs are high.

Solvent recovery is necessary in perc plants due to the higher cost of perchloroethylene. As shown in Figure 4.1-1, recovery is effected on the washer, dryer, still and muck cooker through the use of condensers, water/solvent separators and carbon adsorption units. Typically once a day, solvent in the carbon adsorption unit is desorbed with steam, condensed, separated from the condensed water and returned to the pure solvent storage tank. Residual solvent emitted from treated distillation bottoms and muck is not recovered. As in petroleum plants, good emission control can be obtained by good housekeeping (maintaining all equipment and using good operating practices).

All fluorocarbon machines are of the dry-to-dry variety to conserve solvent vapor, and all are closed systems with built in solvent recovery. High emissions can occur, however, as a result of poor maintenance and operation of equipment. Refrigeration systems are installed on newer machines to recover solvent from the washer/dryer exhaust gases.

Emission factors for dry cleaning operations are presented in Table 4.1-1.

Typical coin operated and commercial plants emit less than 10^6 grams (one ton) per year. Some applications of emission estimates are too broad to identify every small facility. For estimates over large areas, the factors in Table 4.1-2 may be applied for coin operated and commercial dry cleaning emissions.

TABLE 4.1-1. SOLVENT LOSS EMISSION FACTORS FOR DRY CLEANING OPERATIONS

EMISSION FACTOR RATING: B

Solvent Type (Process used)	Source	Emission Rate[a] Typical system kg/100 kg (lb/100 lb)	Well controlled system kg/100 kg (lb/100 lb)
Petroleum (transfer process)	washer/dryer[b]	18	2[c]
	filter disposal		
	uncooked (drained)	8	
	centrifuged		0.5 - 1
	still residue disposal	1	0.5 - 1
	miscellaneous[d]	1	1
Perchloroethylene (transfer process)	washer/dryer/still/muck cooker	8[e]	0.3[c]
	filter disposal		
	uncooked muck	14	
	cooked muck	1.3	0.5 - 1.3
	cartridge filter	1.1	0.5 - 1.1
	still residue disposal	1.6	0.5 - 1.6
	miscellaneous[d]	1.5	1
Trichlorotrifluoroethane (dry-to-dry process)	washer/dryer/still[f]	0	0
	cartridge filter disposal	1	1
	still residue disposal	0.5	0.5
	miscellaneous[d]	1 - 3	1 - 3

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[a] References 1-4. Units are in terms of weight solvent per weight of clothes cleaned (capacity x loads). Emissions also may be estimated by determining the amount of solvent consumed. Assuming that all solvent input is eventually evaporated to the atmosphere, an emission factor of 2000 lb/ton (1000 kg/Mg) of solvent consumed can be applied.

[b] Different material in wash retains a different amount of solvent (synthetics, 10 kg/100 kg; cotton, 20 kg/100 kg; leather, 40 kg/100 kg).

[c] Emissions from washer, dryer, still and muck cooker are passed collectively through a carbon adsorber.

[d] Miscellaneous sources include fugitives from flanges, pumps, pipes and storage tanks, and fixed losses such as opening and closing dryers, etc.

[e] Uncontrolled emissions from washer, dryer, still and muck cooker average about 8 kg/100 kg (8 lb/100 lb). About 15% of solvent emitted is from washer, 75% dryer, 5% each from still and muck cooker.

[f] Based on the typical refrigeration system installed in fluorocarbon plants.

TABLE 4.1-2. PER CAPITA SOLVENT LOSS EMISSION FACTORS FOR DRY CLEANING PLANTS[a]

EMISSION FACTOR RATING: B

Operation	Emission Factors kg/yr/capita (lb/year/cap)	 g/day/capita[b] (lb/day/cap)
Commercial	0.6 (1.3)	1.9 (0.004)
Coin operated	0.2 (0.4)	0.6 (0.001)

[a] References 2-4. All nonmethane VOC.

[b] Assumes a 6 day operating week (313 days/yr).

References for Section 4.1

1. Study To Support New Source Performance Standards for the Dry Cleaning Industry, EPA Contract No. 68-02-1412, TRW, Inc., Vienna, VA, May 1976.

2. Perchloroethylene Dry Cleaners - Background Information for Proposed Standards, EPA-450/3-79-029a, U.S. Environmental Protection Agency, Research Triangle Park, NC, August 1980.

3. Control of Volatile Organic Emissions from Perchloroethylene Dry Cleaning Systems, EPA-450/2-78-050, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1978.

4. Control of Volatile Organic Emissions from Petroleum Dry Cleaners (Draft), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1981.

4.2 SURFACE COATING

Surface coating operations involve the application of paint, varnish, lacquer or paint primer, for decorative or protective purposes. This is accomplished by brushing, rolling, spraying, flow coating and dipping operations. Some industrial surface coating operations include automobile assembly, job enameling and manufacturing of aircraft, containers, furniture, appliances and plastic products. Nonindustrial applications of surface coatings include automobile refinishing and architectural coating of domestic, industrial, government and institutional structures, including building interiors and exteriors and signs and highway markings. Nonindustrial Surface Coating is discussed below in Section 4.2.1, and Industrial Surface Coating in Section 4.2.2.

Emissions of volatile organic compounds (VOC) occur in surface coating operations because of evaporation of the paint vehicles, thinners and solvents used to facilitate the application of coatings. The major factor affecting these emissions is the amount of volatile matter contained in the coating. The volatile portion of most common surface coatings averages about 50 percent, and most, if not all, of this is emitted during the application and drying of the coating. The compounds released include aliphatic and aromatic hydrocarbons, alcohols, ketones, esters, alkyl and aryl hydrocarbon solvents, and mineral spirits. Table 4.2-1 presents general emission factors for surface coating operations.

TABLE 4.2-1. GENERAL EMISSION FACTORS FOR SURFACE COATING APPLICATIONS[a]

EMISSION FACTOR RATING: B

Coating Type	Emissions[b]	
	kg/Mg	lb/ton
Paint	560	1120
Varnish and Shellac	500	1000
Lacquer	770	1540
Enamel	420	840
Primer (zinc chromate)	660	1320

[a] Reference 1.

[b] Nonmethane VOC. Reference 4.

4.2.1 NONINDUSTRIAL SURFACE COATING[1,3,5]

Nonindustrial surface coating operations are nonmanufacturing applications of surface coating. Two major categories are architectural surface coating and automobile refinishing. Architectural uses are considered to include both industrial and nonindustrial structures. Automobile refinishing pertains to the painting of damaged or worn highway vehicle finishes and not the painting of vehicles during manufacture.

Emissions from a single architectural structure or automobile refinishing are calculated by using total volume and content and weight of volatile constituents for the coating employed in the specific application. Estimating emissions for a large area which includes many major and minor applications of nonindustrial surface coatings requires that area source estimates be developed. Architectural surface coating and auto refinishing emissions data are often difficult to compile for a large geographical area. In cases where a large inventory is being developed and/or resources are unavailable for detailed accounting of actual volume of coatings for these applications, emissions may be assumed proportional to population or number of employees. Table 4.2.1-1 presents factors from national emission data and emissions per population or employee for architectural surface coating and automobile refinishing.

TABLE 4.2.1-1. NATIONAL EMISSIONS AND EMISSION FACTORS FOR VOC FROM ARCHITECTURAL SURFACE COATING AND AUTOMOBILE REFINISHING[a]

EMISSION FACTOR RATING: C

Emissions	Architectural Surface Coating	Automobile Refinishing
National		
Mg/yr	446,000	181,000
ton/yr	491,000	199,000
Per capita		
kg/yr (lb/yr)	21.4 (4.6)	0.84 (1.9)
g/day (lb/day)	5.8 (0.013)[b]	2.7 (0.006)[c]
Per employee		
Mg/yr (ton/yr)	-	2.3 (2.6)
kg/day (lb/day)	-	7.4 (16.3)[c]

[a] References 3 and 5 - 8. All nonmethane organics.

[b] Reference 8. Calculated by dividing kg/yr (lb/yr) by 365 days and converting to appropriate units. Assumes that 75% of annual emissions occurs over a 9 month ozone season. For shorter ozone seasons, adjust accordingly.

[c] Assumes a 6 day operating week (313 days/yr).

The use of waterborne architectural coatings reduces volatile organic compound emissions. Current consumption trends indicate increasing substitution of waterborne architectural coatings for those using solvent. Automobile refinishing often is done in areas only slightly enclosed, which makes control of emissions difficult. Where automobile refinishing takes place in an enclosed area, control of the gaseous emissions can be accomplished by the use of adsorbers (activated carbon) or afterburners. The collection efficiency of activated carbon has been reported at 90 percent or greater. Water curtains or filler pads have little or no effect on escaping solvent vapors, but they are widely used to stop paint particulate emissions.

References for Section 4.2.1

1. Air Pollution Engineering Manual, Second Edition, AP-40, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1973. Out of Print.

2. Control Techniques for Hydrocarbon and Organic Gases from Stationary Sources, AP-68, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1969.

3. Control Techniques Guideline for Architectural Surface Coatings (Draft), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1979.

4. Air Pollutant Emission Factors, Contract No. CPA-22-69-119, Resources Research Inc., Reston, VA, April 1970.

5. Procedures for the Preparation of Emission Inventories for Volatile Organic Compounds, Volume I, Second Edition, EPA-450/2-77-028, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1980.

6. W.H. Lamason, "Technical Discussion of Per Capita Emission Factors for Several Area Sources of Volatile Organic Compounds", Monitoring and Data Analysis Division, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 15, 1981. Unpublished.

7. End Use of Solvents Containing Volatile Organic Compounds, EPA-450/3-79-032, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1979.

8. Written communications between Bill Lamason and Chuck Mann, Monitoring and Data Analysis Division, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1980 and March 1981.

9. Final Emission Inventory Requirements for 1982 Ozone State Implementation Plans, EPA-450/4-80-016, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1980.

4.2.2. INDUSTRIAL SURFACE COATING

4.2.2.1 General[1-4]

Process Description - Surface coating is the application of decorative or protective materials in liquid or powder form to substrates. These coatings normally include general solvent type paints, varnishes, lacquers and water thinned paints. After application of coating by one of a variety of methods such as brushing, rolling, spraying, dipping and flow coating, the surface is air and/or heat dried to remove the volatile solvents from the coated surface. Powder type coatings can be applied to a hot surface or be melted after application and caused to flow together. Other coatings can be polymerized after application by thermal curing with infrared or electron beam systems.

Coating Operations - There are both "toll" ("independent") and "captive" surface coating operations. Toll operations fill orders to various manufacturer specifications, and thus change coating and solvent conditions more frequently than do captive companies, which fabricate and coat products within a single facility and which may operate continuously with the same solvents. Toll and captive operations differ in emission control systems applicable to coating lines, because not all controls are technically feasible in toll situations.

Coating Formulations - Conventional coatings contain at least 30 volume percent solvents to permit easy handling and application. They typically contain 70 to 85 percent solvents by volume. These solvents may be of one component or of a mixture of volatile ethers, acetates, aromatics, cellosolves, aliphatic hydrocarbons and/or water. Coatings with 30 volume percent of solvent or less are called low solvent or "high solids" coatings.

Waterborne coatings, which have recently gained substantial use, are of several types: water emulsion, water soluble and colloidal dispersion, and electrocoat. Common ratios of water to solvent organics in emulsion and dispersion coatings are 80/20 and 70/30.

Two part catalyzed coatings to be dried, powder coatings, hot melts, and radiation cured (ultraviolet and electron beam) coatings contain essentially no volatile organic compounds (VOC), although some monomers and other lower molecular weight organics may volatilize.

Depending on the product requirements and the material being coated, a surface may have one or more layers of coating applied. The first coat may be applied to smooth surface imperfections or to assure adhesion of the coating. The intermediate coats usually provide the required color, texture or print, and a clear protective topcoat is often added. General coating types do not differ from those described, although the intended use and the material to be coated determine the composition and resins used in the coatings.

Coating Application Procedures - Conventional spray, which is air atomized and usually hand operated, is one of the most versatile coating methods. Colors can be changed easily, and a variety of sizes and shapes can be painted under many operating conditions. Conventional, catalyzed or waterborne coatings can be applied with little modification. The disadvantages are low efficiency from overspray and high energy requirements for the air compressor.

In hot airless spray, the paint is forced through an atomizing nozzle. Since volumetric flow is less, overspray is reduced. Less solvent is also required, thus reducing VOC emissions. Care must be taken for proper flow of the coating to avoid plugging and abrading of the nozzle orifice. Electrostatic spray is most efficient for low viscosity paints. Charged paint particles are attracted to an oppositely charged surface. Spray guns, spinning discs or bell shaped atomizers can be used to atomize the paint. Application efficiencies of 90 to 95 percent are possible, with good wraparound and edge coating. Interiors and recessed surfaces are difficult to coat, however.

Roller coating is used to apply coatings and inks to flat surfaces. If the cylindrical rollers move in the same direction as the surface to be coated, the system is called a direct roll coater. If they rotate in the opposite direction, the system is a reverse roll coater. Coatings can be applied to any flat surface efficiently and uniformly and at high speeds. Printing and decorative graining are applied with direct rollers. Reverse rollers are used to apply fillers to porous or imperfect substrates, including papers and fabrics, to give a smooth uniform surface.

Knife coating is relatively inexpensive, but is not appropriate for coating unstable materials, such as some knitgoods, or when a high degree of accuracy in the coating thickness is required.

Rotogravure printing is widely used in coating vinyl imitation leathers and wallpaper, and in the application of a transparent protective layer over the printed pattern. In rotogravure printing, the image area is recessed, or "intaglio", relative to the copper plated cylinder on which the image is engraved. The ink is picked up on the engraved area, and excess ink is scraped off the nonimage area with a "doctor blade". The image is transferred directly to the paper or other substrate, which is web fed, and the product is then dried.

Dip coating requires that the surface of the subject be immersed in a bath of paint. Dipping is effective for coating irregularly shaped or bulky items and for priming. All surfaces are covered, but coating thickness varies, edge blistering can occur and a good appearance is not always achieved.

In flow coating, materials to be coated are conveyed through a flow of paint. Paint flow is directed, without atomization, towards the surface through multiple nozzles, then is caught in a trough and recycled. For flat surfaces, close control of film thickness can be maintained by passing the surface through a constantly flowing curtain of paint at a controlled rate.

Emissions and Controls - Essentially all of the VOC emitted from the surface coating industry is from the solvents which are used in the paint formulations, used to thin paints at the coating facility or used for cleanup. All unrecovered solvent can be considered as potential emissions. Monomers and low molecular weight organics can be emitted from those coatings that do not include solvents, but these emissions are essentially negligible.

Emissions from surface coating for an uncontrolled facility can be estimated by assuming that all VOC in the coatings is emitted. Usually, coating consumption volume will be known, and some information about the types of coatings and solvents will be available. The choice of a particular emission factor will depend on the coating data available. If no specific information is given for the coating, it may be estimated from the data in Table 4.2.2.1-2.

TABLE 4.2.2.1-1. VOC EMISSION FACTORS FOR UNCONTROLLED SURFACE COATING[a]

EMISSION FACTOR RATING: B

Available Information on Coating	Emissions of VOC[b] kg/liter of coating	 lb/gal of coating
Conventional or waterborne paints		
VOC, wt % (d)	$\frac{d \cdot \text{coating density}^{c}}{100}$	$\frac{d \cdot \text{coating density}^{c}}{100}$
VOC, vol % (V)	$\frac{V \cdot 0.88^{d}}{100}$	$\frac{V \cdot 7.36^{d}}{100}$
Waterborne paint		
VOC as weight % of total volatiles - including water (X); total volatiles as weight % of coating (d)	$\frac{d \cdot X \cdot \text{coating density}^{c}}{100}$	$\frac{d \cdot X \cdot \text{coating density}^{c}}{100}$
VOC as volume % of total volatiles - including water (Y); total volatiles as volume % of coating (V)	$\frac{V \cdot Y \cdot 0.88^{d}}{100}$	$\frac{V \cdot Y \cdot 7.36^{d}}{100}$

[a] Material balance, when coatings volume use is known.

[b] For special purposes, factors expressed as kg/liter of coating less water may be desired. These may be computed as follows:

$$\frac{\text{Factor as kg/liter of coating}}{1 - \frac{\text{volume \% water}}{100}} = \text{Factor as kg/liter of coating less water}$$

[c] If the coating density is not known, it can be estimated from the information in Table 4.2.2.1-2.

[d] The values 0.88 (kg/liter) and 7.36 (lb/gal) use the average density of solvent in coatings. Use the densities of the solvents in the coatings actually used by the source, if known.

TABLE 4.2.2.1-2. TYPICAL DENSITIES AND SOLIDS CONTENTS OF COATINGS

Type of Coating	Density		Solids
	kg/liter	lb/gal	(% by volume)
Enamel, air dry	0.91	7.6	39.6
Enamel, baking	1.09	9.1	42.8
Acrylic enamel	1.07	8.9	30.3
Alkyd enamel	0.96	8.0	47.2
Primer surfacer	1.13	9.4	49.0
Primer, epoxy	1.26	10.5	57.2
Varnish, baking	0.79	6.6	35.3
Lacquer, spraying	0.95	7.9	26.1
Vinyl, roller coat	0.92	7.7	12.0
Polyurethane	1.10	9.2	31.7
Stain	0.88	7.3	21.6
Sealer	0.84	7.0	11.7
Magnet wire enamel	0.94	7.8	25.0
Paper coating	0.92	7.7	22.0
Fabric coating	0.92	7.7	22.0

[a] Reference 4.

All solvents separately purchased as solvent that are used in surface coating operations and not recovered subsequently can be considered potential emissions. Such VOC emissions at a facility can result from onsite dilution of coatings with solvent, from "makeup solvents" required in flow coating and, in some instances, dip coating, and from the solvents used for cleanup. Makeup solvents are added to coatings to compensate for standing losses, concentration or amount, and thus to bring the coating back to working specifications. Solvent emissions should be added to VOC emissions from coatings to get total emissions from a coating facility.

TABLE 4.2.2.1-3. CONTROL EFFICIENCIES FOR SURFACE COATING OPERATIONS[a]

Control Option	Reduction[b] (%)
Substitute waterborne coatings	60-95
Substitute low solvent coatings	40-80
Substitute powder coatings	92-98
Add afterburners/incinerators	95

[a] References 1-3.

[b] Expressed as % of total uncontrolled emission load.

Typical ranges of control efficiencies are given in Table 4.2.2.1-3. Emission controls normally fall under one of three categories - modifications in paint formula, process changes, or addon controls. These are discussed further in the specific subsections which follow.

4.2.2.2 Coil and Can Coating[5-8]

Process Description - Coil coating is the coating of any flat metal sheet or strip that comes in rolls or coils. Cans are made from two or three flat pieces of metal, so can coating is included within this broad category, as are the coating of screens, fencing, metal doors, aluminum siding and a variety of other products. Figure 4.2.2.2-1 shows a typical coil coating line, and Figure 4.2.2.2-2 depicts a three piece can sheet printing operation.

There are both "toll" and "captive" coil coating operations. The former fill orders to customer specifications, and the latter coat the metal for products fabricated within one facility. Some coil coating operations do both toll and captive work.

Coil coating lines have one or more coaters, each followed by an oven (see Figure 4.2.2.2-1). The metal is cleaned and treated for corrosion protection and proper coating adhesion (see Section 4.6, Solvent Degreasing). The prime coat is applied, on one or both sides, by three or more powered rollers. This coating is dried or baked, then is cooled in a quench chamber, either by a spray of water or by a blast of air followed by water. It is usually reverse roller coated. A prime or single coat may also be applied by electrodeposition, when a waterborne coating is used.

Oven temperatures range from 40 to 380°C (100 to 1000°F), depending on the type and desired thickness of the coating and on the type of metal being coated. A topcoat may be applied and cured in a similar manner.

In can coating, as with coil coating, there are both toll and captive manufacturers. Some plants coat metal sheets, some make three piece cans, some fabricate and coat two piece cans, and some fabricate can ends. Others perform combinations of these processes.

Cans may be made from a rectangular sheet (body blank) and two circular ends ("three piece" cans) or they can be drawn and wall ironed from a shallow cup to which an end is attached after the can is filled ("two piece" cans). There are major differences in coating practices, depending on the type of can and the product packaged in it.

Three piece can manufacturing involves sheet coating and can fabricating. Sheet coating includes base coating and printing or lithographing, followed by curing at tmeperatures of up to 220°C

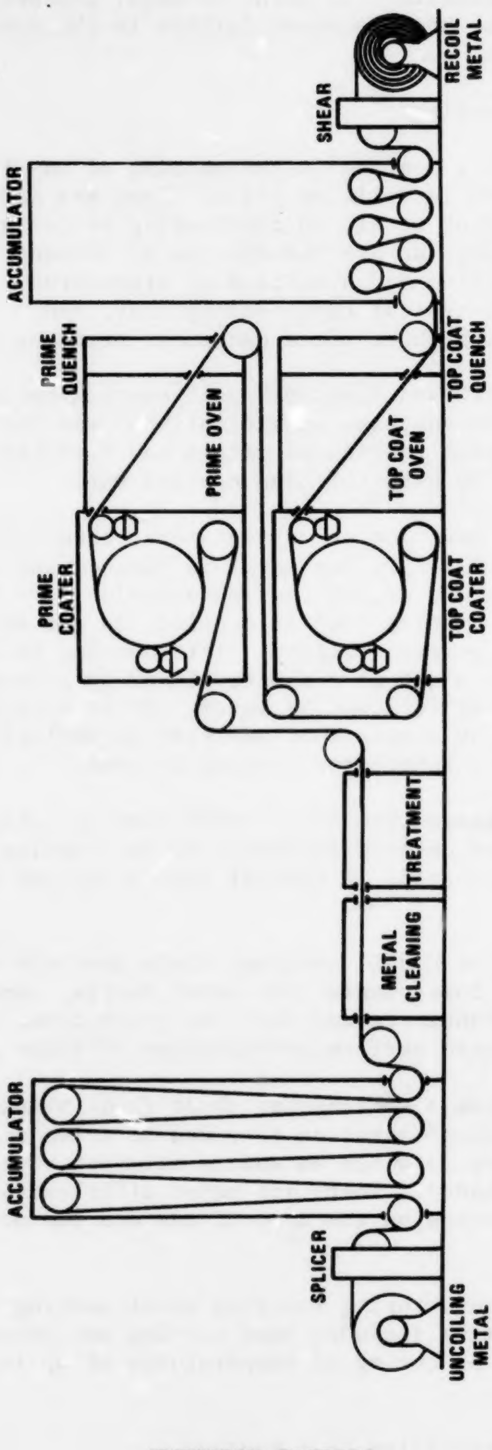
UNCOILING METAL
SPLICER
ACCUMULATOR
METAL CLEANING
TREATMENT
PRIME COATER
PRIME OVEN
PRIME QUENCH
TOP COAT COATER
TOP COAT OVEN
TOP COAT QUENCH
ACCUMULATOR
SHEAR
RECOIL METAL

Figure 4.2.2.2-1. Coil coating line emissions.[7]

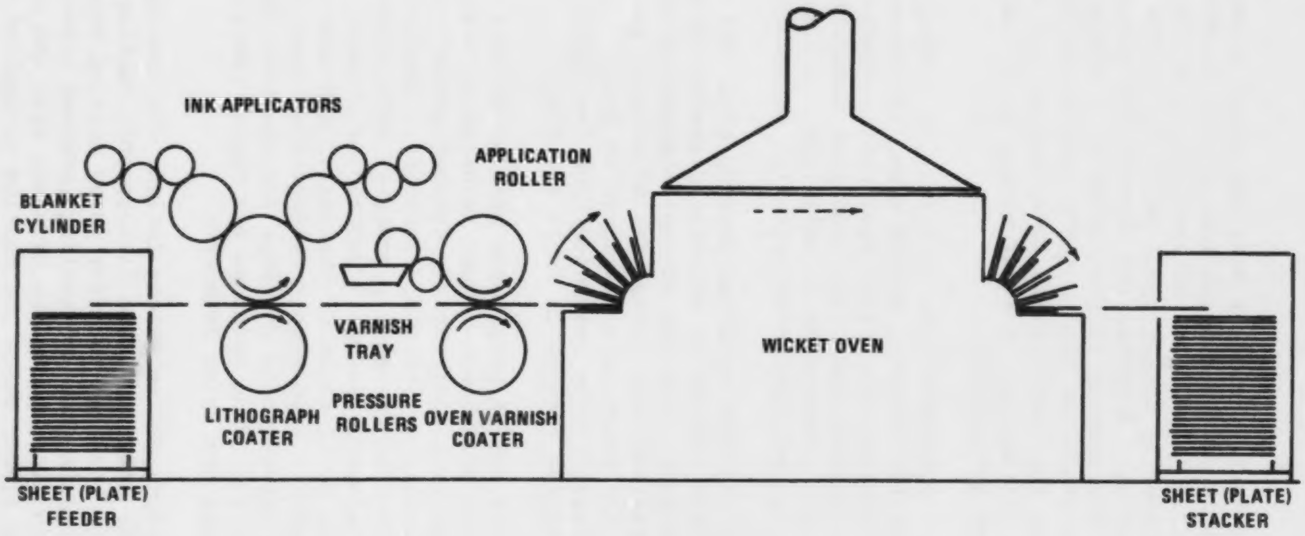
INK APPLICATORS
BLANKET CYLINDER
APPLICATION ROLLER
VARNISH TRAY
PRESSURE ROLLERS
LITHOGRAPH COATER
OVEN VARNISH COATER
WICKET OVEN
SHEET (PLATE) FEEDER
SHEET (PLATE) STACKER

Figure 4.2.2.2-2. Three piece can sheet printing operation.[7]

(425°F). When the sheets have been formed into cylinders, the seam is sprayed, usually with a lacquer, to protect the exposed metal. If they are to contain an edible product, the interiors are spray coated, and the cans baked at up to 220°C (425°F). See Figure 4.2.2.2-2.

Two piece cans are largely used by beer and other beverage industries. The exteriors may be reverse roll coated in white and cured at 170 to 200°C (325 to 400°F). Several colors of ink are then transferred (sometimes by lithographic printing) to the cans as they rotate on a mandrel. A protective varnish may be roll coated over the inks. The coating is then cured in a single or multipass oven at temperatures of 180 to 200°C (350 to 400°F). The cans are spray coated on the interior and spray and/or roll coated on the exterior of the bottom end. A final baking at 110 to 200°C (225 to 400°F) completes the process.

Emissions and Controls - Emissions from coil and can coating operations depend on composition of the coating, coated area, thickness of coat and efficiency of application. Post-application chemical changes, and nonsolvent contaminants like oven fuel combustion products, may also affect the composition of emissions. All solvent used and not recovered can be considered potential emissions.

Coil coating emissions come from the coating area, the oven and the quench area. They consist of volatile organics and other compounds, such as aldehydes, from the thermal degradation of volatile organics. Emissions from combustion of natural gas, generally used to heat the ovens, are discussed in Section 1.4. Emissions from coil coating can be estimated from the amount of coating applied by using the factors in Table 4.2.2.1-1.

Incineration and the use of waterborne and low solvent coatings both reduce organic vapor emissions. Other technically feasible control options, such as electrostatically sprayed powder coatings, are not presently applicable to the whole industry. Catalytic and thermal incinerators both can be used, preferably with primary and/or secondary heat recovery systems. Waterborne primers, backers (coatings on the reverse or backside of the coil), and some waterborne low to medium gloss topcoats have been developed that equal the performance of organic solventborne coatings for aluminum but have not yet been applied at full line speed in all cases. Waterborne coatings for other metals are being developed.

Sources of can coating VOC emissions include the coating area and the oven area of the sheet base and lithographic coating lines, the three piece can side seam and interior spray coating processes, and the two piece can coating and end sealing compound lines. Emission rates vary with line speed, can or sheet size and coating type. On sheet coating lines, where the coating is applied by

TABLE 4.2.2.2-1. VOC EMISSION FACTORS FOR CAN COATING PROCESSES[a]

EMISSION FACTOR RATING: B

Process	Typical emissions from coating line[b]		Estimated fraction from coater area (%)	Estimated fraction from oven (%)	Typical organic emissions[c]	
	lb/hr	kg/hr			Mg/yr	ton/yr
Three piece can sheet base coating line	112	51	9-12	88-91	160	176
Three piece can sheet lithographic coating line	65	30	8-11	89-92	50	55
Three piece beer and beverage can - side seam spray coating process	12	5	100	air dried	18	20
Three piece beer and beverage can - interior body spray coating process	54	25	75-85	15-25	80	88
Two piece can coating line	86	39	NA	NA	260	287
Two piece can end sealing compound line	8	4	100	air dried	14	15

---

[a] Reference 7. NA = not available.

[b] Organic solvent emissions will vary according to line speed, size of can or sheet being coated, and type of coating used.

[c] Based upon normal operating conditions.

rollers, most solvent evaporates in the oven. For other coating processes, the coating operation itself is the major source. Emissions can be estimated from the amount of coating applied by using the factors in Table 4.2.2.1-1 or, if the number and general nature of the coating lines is known, from Table 4.2.2.2-1.

Available control technology includes the use of addon devices like incinerators and carbon adsorbers and the conversion to low solvent and ultraviolet curable coatings. Thermal and catalytic incinerators both may be used to control emissions from three piece can sheet base coating lines, sheet lithographic coating lines, and interior spray coating. Incineration is applicable to two piece can coating lines. Carbon adsorption is most acceptable to low temperature processes which use a limited number of solvents. Such processes include two and three piece can interior spray coating, two piece can end sealing compound lines, and three piece can side seam spray coating.

Low solvent coatings are not yet available to replace all the organic solventborne formulations presently used in the can industry. Waterborne basecoats have been successfully applied to two piece cans. Powder coating technology is used for side seam coating of noncemented three piece cans.

Ultraviolet curing technology is available for rapid drying of the first two colors of ink on three piece can sheet lithographic coating lines.

Table 4.2.2.2-2 shows control efficiencies for typical coil and can coating lines.

4.2.2.3 Magnet Wire Coating[9]

Process Description - Magnet wire coating is applying a coat of electrically insulating varnish or enamel to aluminum or copper wire used in electrical machinery. The wire is usually coated in large plants that both draw and insulate it and then sell it to electrical equipment manufacturers. The wire coating must meet rigid electrical, thermal and abrasion specifications.

Figure 4.2.2.3-1 shows a typical wire coating operation. The wire is unwound from spools and passed through an annealing furnace. Annealing softens the wire and cleans it by burning off oil and dirt. Usually, the wire then passes through a bath in the coating applicator and is drawn through an orifice or coating die to scrape off the excess. It is then dried and cured in a two zone oven at 200°, then 430°C (400 and 806°F). Wire may pass through the coating applicator and the oven as many as twelve times to acquire the necessary thickness of coating.

TABLE 4.2.2.2-2. CONTROL EFFICIENCIES FOR COIL AND CAN COATING LINES[a]

Affected Facility[b]	Control Option	Reduction[c] (%)
Coil Coating Lines	Thermal incineration	90-98
	Catalytic incineration	90
	Waterborne and high solids coating	70-95
Two Piece Can Lines		
Exterior coating	Thermal and catalytic incineration	90
	Waterborne and high solids coating	60-90
	Ultraviolet curing	up to 100
Interior spray coating	Thermal and catalytic incineration	90
	Waterborne and high solids coating	60-90
	Powder coating	100
	Carbon adsorption	90
Three Piece Can Lines		
Sheet coating lines		
Exterior coating	Thermal and catalytic incineration	90
	Waterborne and high solids coating	60-90
	Ultraviolet curing	up to 100
Interior spray coating	Thermal and catalytic incineration	90
	Waterborne and high solids coating	60-90
Can fabricating lines		
Side seam spray coating	Waterborne and high solids coating	60-90
	Powder (only for uncemented seams)	100
Interior spray coating	Thermal and catalytic incineration	90
	Waterborne and high solids coating	60-90
	Powder (only for uncemented seams)	100
	Carbon adsorption	90
End Coating Lines		
Sealing compound	Waterborne and high solids coating	70-95
Sheet coating	Carbon adsorption	90
	Thermal and catalytic incineration	90
	Waterborne and high solids coating	60-90

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[a] Reference 7.

[b] Coil coating lines consist of coaters, ovens and quench areas. Sheet, can and end wire coating lines consist of coaters and ovens.

[c] Compared to conventional solvent base coatings used without any added controls.

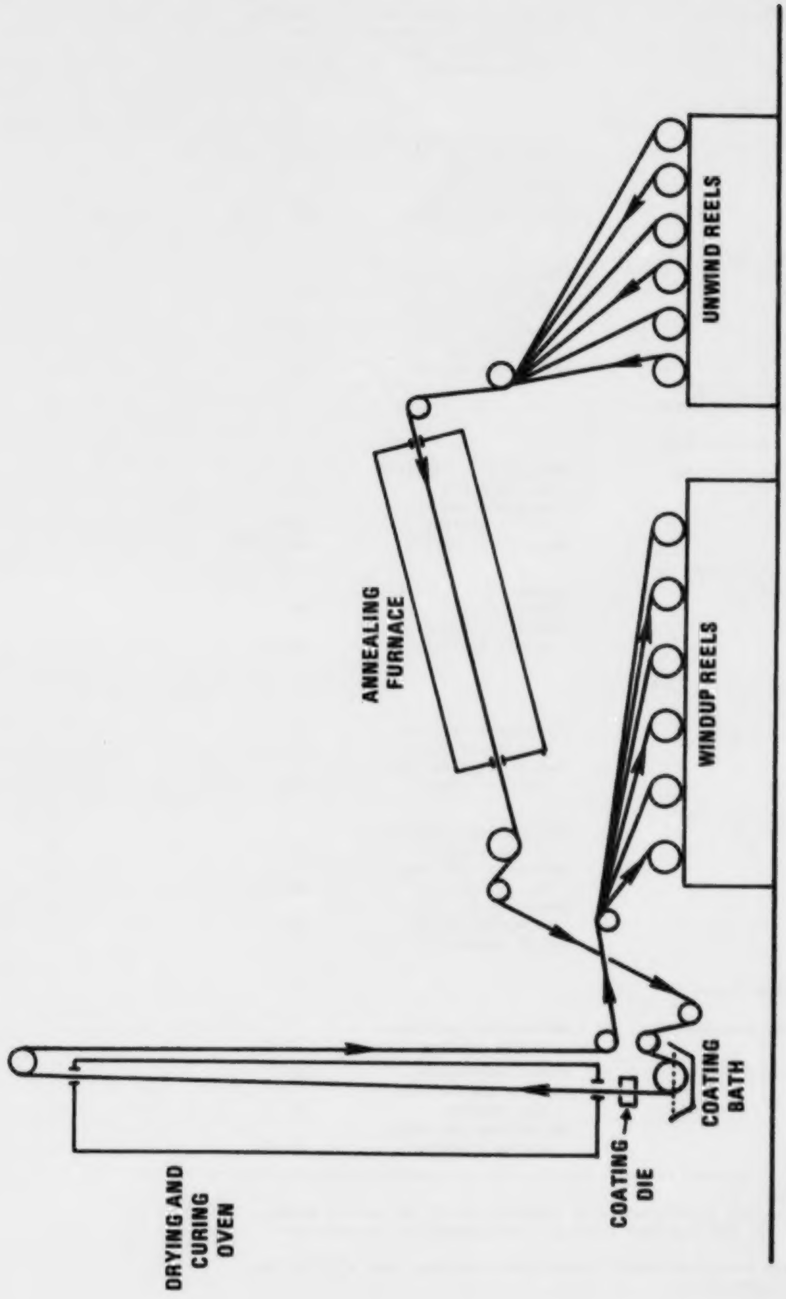
DRYING AND CURING OVEN
COATING DIE
COATING BATH
ANNEALING FURNACE
WINDUP REELS
UNWIND REELS

Figure 4.2.2.3-1. Wire coating line emission points.[9]

Emissions and Controls - Emissions from wire coating operations depend on composition of the coating, thickness of coat and efficiency of application. Postapplication chemical changes, and nonsolvent contaminants such as oven fuel combustion products, may also affect the composition of emissions. All solvent used and not recovered can be considered potential emissions.

The exhaust from the oven is the most important source of solvent emissions in the wire coating plant. Emissions from the applicator are comparatively low because a dip coating technique is used. See Figure 4.2.2.3-1.

VOC emissions may be estimated from the factors in Table 4.2.2.1-1, if the coating usage is known and if the coater has no controls. Most wire coaters built since 1960 do have controls, so the information in the following paragraph may be applicable. Table 4.2.2.3-1 gives estimated emissions for a typical wire coating line.

Incineration is the only commonly used technique to control emissions from wire coating operations. Since about 1960, all major wire coating designers have incorporated catalytic incinerators into their oven designs, because of the economic benefits. The internal catalytic incinerator burns solvent fumes and circulates heat back into the wire drying zone. Fuel otherwise needed to operate the oven is eliminated or greatly reduced, as are costs. Essentially all solvent emissions from the oven can be directed to an incinerator with a combustion efficiency of at least 90 percent.

TABLE 4.2.2.3-1. ORGANIC SOLVENT EMISSIONS FROM A TYPICAL WIRE COATING LINE[a]

Coating Line[b]		Annual Totals[c]	
kg/hr	lb/hr	Mg/yr	ton/yr
12	26	84	93

[a] Reference 9.

[b] Organic solvent emissions vary from line to line by size and speed of wire, number of wires per oven, and number of passes through the oven. A typical line may coat 1,200 pounds of wire per day. A plant may have many lines.

[c] Based upon normal operating conditions of 7,000 hr/yr for one line without incinerator.

Ultraviolet cured coatings are available for special systems. Carbon adsorption is not practical. Use of low solvent coatings is only a potential control, because they have not yet been developed with properties that meet industry's requirements.

4.2.2.4 Other Metal Coating[11-13]

Process Description - Large appliance, metal furniture and miscellaneous metal parts and products coating lines have many common operations, similar emissions and emission points, and available control technology. Figure 4.2.2.4-1 shows a typical metal furniture coating line.

Large appliances include doors, cases, lids, panels and interior support parts of washers, dryers, ranges, refrigerators, freezers, water heaters, air conditioners and associated products. Metal furniture includes both outdoor and indoor pieces manufactured for household, business or institutional use. "Miscellaneous parts and products" herein denotes large and small farm machinery, small appliances, commercial and industrial machinery, fabricated metal products and other industries that coat metal under Standard Industrial Classification (SIC) codes 33 through 39.

Large Appliances - The coatings applied to large appliances are usually epoxy, epoxy/acrylic or polyester enamels for the primer or single coat, and acrylic enamels for the topcoat. Coatings containing alkyd resins are also used. Prime and interior single coats are applied at 25 to 36 volume percent solids. Topcoats and exterior single coats are applied at 30 to 40 volume percent. Lacquers may be used to touch up any scratches that occur during assembly. Coatings contain 2 to 15 solvents, typical of which are esters, ketones, aliphatics, alcohols, aromatics, ethers and terpenes.

Small parts are generally dip coated, and flow or spray coating is used for larger parts. Dip and flow coating are performed in an enclosed room vented either by a roof fan or by an exhaust system adjoining the drain board or tunnel. Down or side draft booths remove overspray and organic vapors from prime coat spraying. Spray booths are also equipped with dry filters or a water wash to trap overspray.

Parts may be touched up manually with conventional or airless spray equipment. Then they are sent to a flashoff area (either open or tunneled) for about 7 minutes and are baked in a multipass oven for about 20 minutes at 180 to 230°C (350 to 450°F). At that point, large appliance exterior parts go on to the topcoat application area, and single coated interior parts are moved to the assembly area of the plant.

The topcoat, and sometimes primers, are applied by automated electrostatic disc, bell or other types of spray equipment. Topcoats often are more than one color, changed by automatically flushing out the system with solvent. Both the topcoat and touchup spray areas are designed with side or down draft exhaust control. The parts go through about a 10 minute flashoff period, followed by baking in a multipass oven for 20 to 30 minutes at 140 to 180°C (270 to 350°F).

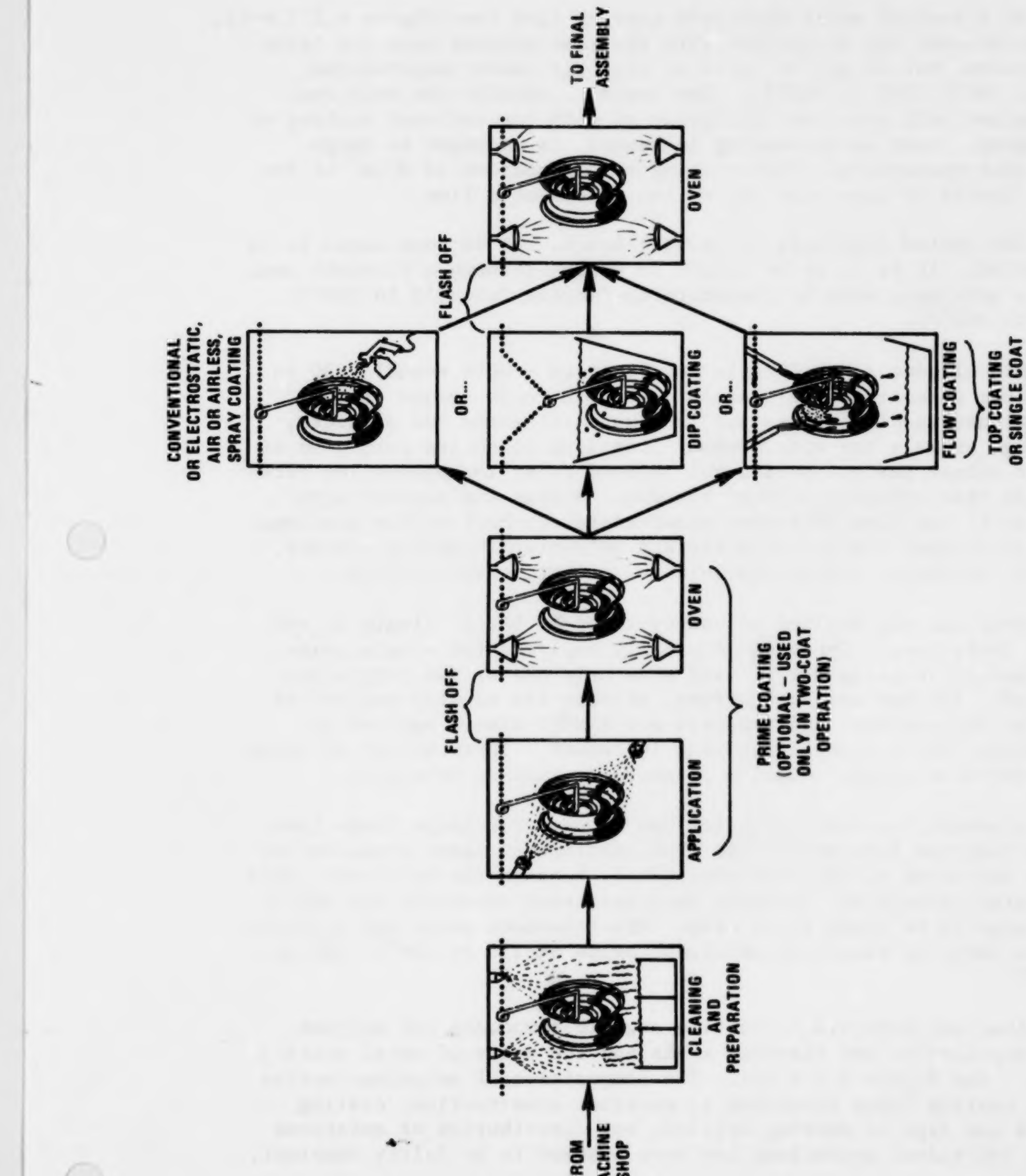
FROM MACHINE SHOP
CLEANING AND PREPARATION
APPLICATION
FLASH OFF
OVEN
PRIME COATING (OPTIONAL – USED ONLY IN TWO-COAT OPERATION)
CONVENTIONAL OR ELECTROSTATIC, AIR OR AIRLESS, SPRAY COATING
OR...
DIP COATING
OR...
FLOW COATING
TOP COATING OR SINGLE COAT OPERATION
FLASH OFF
OVEN
TO FINAL ASSEMBLY

Figure 4.2.2.4-1 Metal product coating line emission points.11

Metal Furniture - Most metal furniture coatings are enamels, although some lacquers are used. The most common coatings are alkyds, epoxies and acrylics, which contain the same solvents used in large appliance coatings, applied at about 25 to 35 percent solids.

On a typical metal furniture coating line (see Figure 4.2.2.4-1), the prime coat can be applied with the same methods used for large appliances, but it may be cured at slightly lower temperatures, 150 to 200°C (300 to 400°F). The topcoat, usually the only coat, is applied with electrostatic spray or with conventional airless or air spray. Most spray coating is manual, in contrast to large appliance operations. Flow coating or dip coating is done, if the plant generally uses only one or two colors on a line.

The coated furniture is usually baked, but in some cases it is air dried. If it is to be baked, it passes through a flashoff area into a multizone oven at temperatures ranging from 150 to 230°C (300 to 450°F).

Miscellaneous Metal Parts and Products - Both enamels (30 to 40 volume percent solids) and lacquers (10 to 20 volume percent solids) are used to coat miscellaneous metal parts and products, although enamels are more common. Coatings often are purchased at higher volume percent solids but thinned prior to application (frequently with aromatic solvent blends). Alkyds are popular with industrial and farm machinery manufacturers. Most of the coatings contain several (up to 10) different solvents, including ketones, esters, alcohols, aliphatics, ethers, aromatics and terpenes.

Coatings are applied in conveyorized or batch, single or two coat, operations. Spraying is usually employed for single coats. Flow and dip coating may be used when only one or two colors are applied. For two coat operations, primers are usually applied by flow or dip coating, and topcoats are almost always applied by spraying. Electrostatic spraying is common. Spray booths or areas are kept at a slight negative pressure to capture overspray.

A manual two coat operation may be used for large items like industrial and farm machinery. The coatings on large products are often air dried rather than oven baked, because the machinery, when completely assembled, includes heat sensitive materials and may be too large to be cured in an oven. Miscellaneous parts and products can be baked in single or multipass ovens at 150 to 230°C (300 to 450°F).

Emissions and Controls - Volatile organic compounds are emitted from application and flashoff areas and the ovens of metal coating lines. See Figure 4.2.2.4-1. The composition of emissions varies among coating lines according to physical construction, coating method and type of coating applied, but distribution of emissions among individual operations has been assumed to be fairly constant, regardless of the type of coating line or the specific product coated, as Table 4.2.2.4-2 indicates. All solvent used can be considered potential emissions. Emissions can be calculated from the factors in Table 4.2.2.1-1 if coatings use is known, or from the factors in Table 4.2.2.4-2 if only a general description of the plant is available. For emissions from the cleansing and pretreatment area, see Section 4.6, Solvent Degreasing.

When powder coatings, which contain almost no VOC, are applied to some metal products as a coating modification, emissions are greatly reduced. Powder coatings are applied as single coats on some large appliance interior parts and as topcoat for kitchen ranges. They are also used on metal bed and chair frames, shelving and stadium seating, and they have been applied as single coats on small appliances, small farm machinery, fabricated metal product parts and industrial machinery components. The usual application method is manual or automatic electrostatic spray.

Improving transfer efficiency is a method of reducing emissions. One such technique is the electrostatic application of the coating, and another is dip coating with waterborne paint. For example, many makers of large appliances are now using electrodeposition to apply prime coats to exterior parts and single coats to interiors, because this technique increases corrosion protection and resistance to detergents. Electrodeposition of these waterborne coatings is also being used at several metal furniture coating plants and at some farm, commercial machinery and fabricated metal products facilities.

Automated electrostatic spraying is most efficient, but manual and conventional methods can be used, also. Roll coating is another option on some miscellaneous parts. Use of higher solids coatings is a practiced technique for reduction of VOC emissions.

Carbon adsorption is technically feasible for collecting emissions from prime, top and single coat applications and flashoff areas. However, the entrained sticky paint particles are a filtration problem, and adsorbers are not commonly used.

Incineration is used to reduce organic vapor emissions from baking ovens for large appliances, metal furniture and miscellaneous products, and it is an option for control of emissions from application and flashoff areas.

Table 4.2.2.4-1 gives estimated control efficiencies for large appliance, metal furniture and miscellaneous metal part and product coating lines, and Table 4.2.2.4-2 gives their emission factors.

4.2.2.5 Flat Wood Interior Panel Coating

Process Description[14] - Prefinished flat wood construction products are interior panels made of hardwood plywoods (natural and lauan), particle board, and hardboard.

TABLE 4.2.2.4-1. ESTIMATED CONTROL TECHNOLOGY EFFICIENCIES FOR METAL COATING LINES[a]

Control Technology	Application			Organic Emissions Reduction (%)		
	Large appliances	Metal furniture	Miscellaneous	Large appliances	Metal furniture	Miscellaneous
Powder	Top, exterior or interior single coat	Top or single coat	Oven baked single coat or topcoat	95-99[b]	95-99[b]	95-98[c]
Waterborne (spray, dip, flowcoat)	All applications	Prime, top or single coat	Oven baked single coat, primer and topcoat; air dried primer and topcoat	70-90[b]	60-90[b]	60-90[c]
Waterborne (electrodeposition)	Prime or interior single coat	Prime or single coat	Oven baked single coat and primer	90-95[b]	90-95[b]	90-95[c]
Higher solids (spray)	Top or exterior single coat and sound deadener	Top or single coat	Oven baked single coat and topcoat; air dried primer and topcoat	60-80[b]	50-80[b]	50-80[c]
Carbon adsorption	Prime, single or topcoat application and flashoff areas	Prime, top or single coat application and flashoff areas	Oven baked single coat, primer and topcoat application and flashoff areas; air dried primer and topcoat application and drying areas	90[d]	90[d]	90[d]
Incineration	Prime, top or single coat ovens	Ovens	Ovens	90[d]	90[d]	90+[d]

[a] References 11-13.

[b] The base case against which these percent reductions were calculated is a high organic solvent coating which contains 25 volume % solids and 75 volume % organic solvents. Transfer efficiencies for liquid coatings were assumed to be about 80% for spray and 90% for dip or flowcoat, for powders about 93%, and for electrodeposition, 99%.

[c] Figures reflect the range of reduction possible. Actual reduction achieved depends on compositions of the conventional coating originally used and replacement low organic solvent coating, on transfer efficiency, and on relative film thicknesses of the two coatings.

[d] Reduction is only across the control device and does not account for capture efficiency.

TABLE 4.2.2.4-2. EMISSION FACTORS FOR TYPICAL METAL COATING PLANTS[a]

EMISSION FACTOR RATING: B

Type of Plant	Production Rate	Emissions		Estimated Emissions (%)	
		Mg/yr	ton/yr	Application and Flashoff	Ovens
Large appliances					
Prime and topcoat spray	768,000 units/yr	315	347	80	20
Metal furniture[b]					
Single spray[c]	48×10^6 ft^2/yr	500	550	65 - 80	20 - 35
Single dip[d]	23×10^6 ft^2/yr	160	176	50 - 60	40 - 50
Miscellaneous metal[b]					
Conveyor single flow[d]	16×10^6 ft^2/yr	111	122	50 - 60	40 - 50
Conveyor single dip	" "	111	122	40 - 50	50 - 60
Conveyor single spray[e]	" "	200	220	70 - 80	20 - 30
Conveyor two coat, flow and spray	" "	311	342	60 - 70	30 - 40
Conveyor two coat, dip and spray	" "	311	342	60 - 70	30 - 40
Conveyor two coat, spray	" "	400	440	70 - 80	20 - 30
Manual two coat, spray and air dry	8.5×10^6 ft^2/yr	212	233	100	0

[a] References 11-13, 17.

[b] Estimated from area coated, assumed dry coating thickness of 1 mil, coating of 75% solvent by volume and 25% solids by volume, appropriate transfer efficiency (TE), and solvent density of 0.88 kg/liter (7.36 lb/gal). The equation to be used is:

$$E\ (\text{tons/yr}) = 2.29 \times 10^{-6}\ \text{area coated}\ (\text{ft}^2)\ \frac{V}{100 - V}\ \frac{1}{TE}$$

or

$$E\ (\text{Mg/yr}) = 2.09 \times 10^{-6}\ \text{area coated}\ (\text{ft}^2)\ \frac{V}{100 - V}\ \frac{1}{TE}$$

where V = VOC as volume %.

[c] Transfer efficiency assumed to be 60%, presuming the coater uses manual electrostatic equipment.

[d] Flow and dip coat transfer efficiencies assumed to be 90%.

[e] Transfer efficiency assumed to be 50%, presuming the coater uses electrostatic equipment but coats a wide range of product sizes and configurations.

Fewer than 25 percent of the manufacturers of such flat wood products coat the products in their plants, and in some of the plants that do coat, only a small percentage of total production is coated. At present, most coating is done by toll coaters who receive panels from manufacturers and undercoat or finish them according to customer specifications and product requirements.

Some of the layers and coatings that can be factory applied to flat woods are filler, sealer, groove coat, primer, stain, basecoat, ink and topcoat. Solvents used in organic base flat wood coatings are usually component mixtures, including methyl ethyl ketone, methyl isobutyl ketone, toluene, xylene, butyl acetates, propanol, ethanol, butanol, naphtha, methanol, amyl acetate, mineral spirits, SoCal I and II, glycols, and glycol ethers. Those most often used in water-borne coatings are glycol, glycol ethers, propanol and butanol.

Various forms of roll coating are the preferred techniques for applying coatings to flat woods. Coatings used for surface cover can be applied with a direct roller coater, and reverse roll coaters are generally used to apply fillers, forcing the filler into panel cracks and voids. Precision coating and printing (usually with offset gravure grain printers) are also forms of roll coating, and several types of curtain coating may be employed, also (usually for topcoat application). Various spray techniques and brush coating may be used, too.

Printed interior panelings are produced from plywoods with hardwood surfaces (primarily lauan) and from various wood composition panels, including hardboard and particle board. Finishing techniques are used to cover the original surface and to produce various decorative effects. Figure 4.2.2.5-1 is a flow diagram showing some, but not all, typical production line variations for printed interior paneling.

Groove coatings, applied in different ways and at different points in the coating procedure, are usually pigmented low resin solids reduced with water prior to use, therefore yielding few, if any, emissions. Fillers, usually applied by reverse roll coating, may be of various formulations: (1) polyester (which is ultraviolet cured), (2) water base, (3) lacquer base, (4) polyurethane and (5) alkyd urea base. Water base fillers are in common use on printed paneling lines.

Sealers may be of water or solvent base, usually applied by airless spray or direct roll coating, respectively. Basecoats, which are usually direct roll coated, generally are of lacquer, synthetic, vinyl, modified alkyd urea, catalyzed vinyl, or water base.

Inks are applied by an offset gravure printing operation similar to direct roll coating. Most lauan printing inks are pigments dispersed in alkyd resin, with some nitrocellulose added for

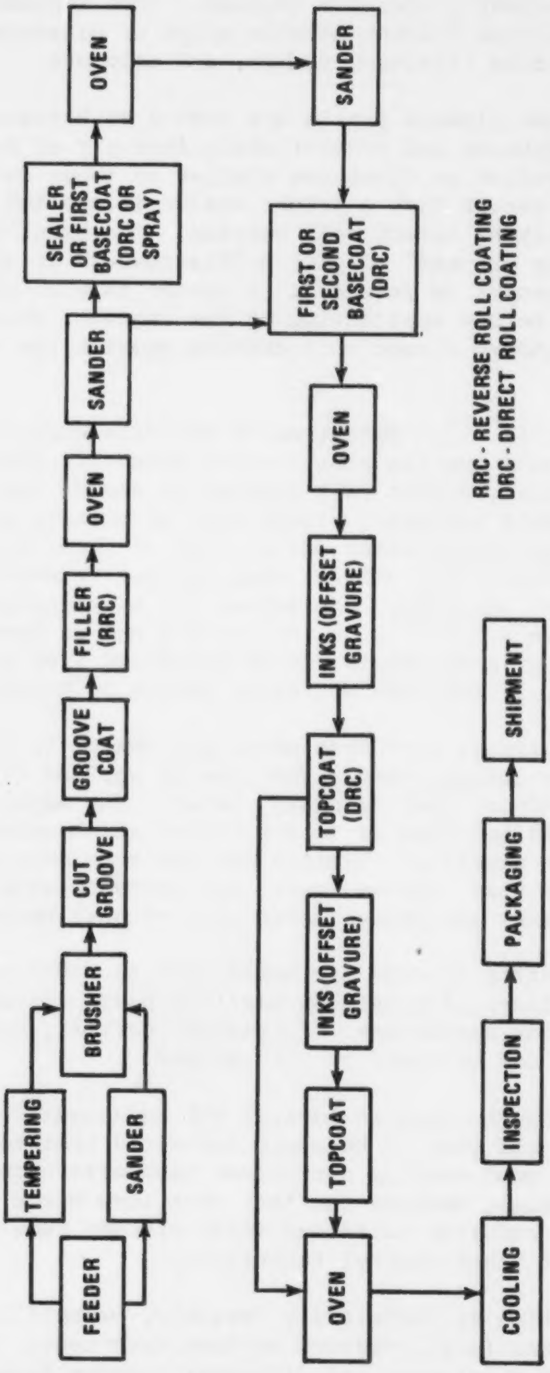
FEEDER
TEMPERING
SANDER
BRUSHER
CUT GROOVE
GROOVE COAT
FILLER (RRC)
OVEN
SANDER
SEALER OR FIRST BASECOAT (DRC OR SPRAY)
OVEN
SANDER
FIRST OR SECOND BASECOAT (DRC)
OVEN
INKS (OFFSET GRAVURE)
TOPCOAT (DRC)
INKS (OFFSET GRAVURE)
TOPCOAT
OVEN
COOLING
INSPECTION
PACKAGING
SHIPMENT
RRC - REVERSE ROLL COATING
DRC - DIRECT ROLL COATING

Figure 4.2.2.5-1. Flatwood interior panel coating line emission points.14

better wipe and printability. Water base inks have a good future for clarity, cost and ecology reasons. After printing, a board goes through one or two direct or precision roll coaters for application of the clear protective topcoat. Some topcoats are synthetic, prepared from solvent soluble alkyd or polyester resins, urea formaldehyde cross linkings, resins, and solvents.

Natural hardwood plywood panels are coated with transparent or clear finishes to enhance and protect their face ply of hardwood veneer. Typical production lines are similar to those for printed interior paneling, except that a primer sealer is applied to the filled panel, usually by direct roll coating. The panel is then embossed and "valley printed" to give a "distressed" or antique appearance. No basecoat is required. A sealer is also applied after printing but before application of the topcoat, which may be curtain coated, although direct roll coating remains the usual technique.

Emissions and Controls[8,14] - Emissions of volatile organic compounds at flat wood coating plants occur primarily from reverse roll coating of filler, direct roll coating of sealer and basecoat, printing of wood grain patterns, direct roll or curtain coating of topcoat(s), and oven drying after one or more of these operations (see Figure 4.2.2.5-1). All solvent used and not recovered can be considered potential emissions. Emissions can be calculated from the factors in Table 4.2.2.1-1, if the coating use is known. Emissions for interior printed panels can be estimated from the factors in Table 4.2.2.5-1, if the area of coated panels is known.

Waterborne coatings, a process materials change to reduce emissions, are increasingly used. They can be applied to almost all flat wood except redwood and, possibly, cedar. The major use of waterborne flat wood coatings is in the filler and basecoat applied to printed interior paneling. Limited use has been made of waterborne materials for inks, groove coats, and topcoats with printed paneling, and for inks and groove coats with natural hardwood panels.

Ultraviolet curing systems are applicable to clear or semitransparent fillers, topcoats on particle board coating lines, and specialty coating operations. Polyester, acrylic, urethane and alkyd coatings can be cured by this method.

Afterburners can be used to control VOC emissions from baking ovens, and there would seem to be ample recovered heat to use. Extremely few flat wood coating operations have afterburners as addon controls, though, despite the fact that they are a viable control option for reducing emissions where product requirements restrict the use of other control techniques.

Carbon adsorption is technically feasible, especially for specific applications (e.g., redwood surface treatment), but the use of multicomponent solvents and different coating formulations

TABLE 4.2.2.5-1. VOC EMISSION FACTORS FOR INTERIOR PRINTED PANELS[a]

EMISSION FACTOR RATING: B

Paint Category	Coverage[b]				Uncontrolled VOC Emissions					
	liter/100 m^2		gal/1,000 ft^2		kg/100 m^2 coated			lb/1,000 ft^2 coated		
	Water borne	Conventional paint	Water borne	Conventional paint	Water borne	Conventional paint	Ultra-violet[c]	Water borne	Conventional paint	Ultra-violet[c]
Filler	6.5	6.9	1.6	1.7	0.3	3.0	neg	0.6	6.1	neg
Sealer	1.4	1.2	0.35	0.3	0.2	0.5	0	0.4	1.1	0
Basecoat	2.6	3.2	0.65	0.8	0.2	2.4	0.24	0.5	5.0	0.5
Ink	0.4	0.4	0.1	0.1	0.1	0.3	0.10	0.2	0.6	0.2
Topcoat	2.6	2.8	0.65	0.7	0.4	1.8	neg	0.8	3.7	neg
Total	13.5	14.5	3.4	3.6	1.2	8.0	0.4	2.5	16.5	0.8

[a] Reference 14. Organics are all nonmethane. Neg = negligible.

[b] Reference 1. From Abitibi Corp., Cucamonga, CA. Adjustments between water and conventional paints made using typical nonvolatiles content.

[c] UV line uses no sealer, uses waterborne basecoat and ink. Total adjusted to cover potential emissions from UV coatings.

in several steps along the coating line have thus far precluded its use to control flat wood coating emissions and to reclaiming solvents. The use of low solvent coatings to fill pores and to seal wood has been demonstrated.

4.2.2.6 Paper Coating

Process Description[5,7] - Paper is coated for various decorative and functional purposes with waterborne, organic solventborne, or solventless extruded materials. Paper coating is not to be confused with printing operations, which use contrast coatings that must show a difference in brightness from the paper to be visible. Coating operations are the application of a uniform layer or coating across a substrate. Printing results in an image or design on the substrate.

Waterborne coatings improve printability and gloss but cannot compete with organic solventborne coatings in resistance to weather, scuff and chemicals. Solventborne coatings, as an added advantage, permit a wide range of surface textures. Most solventborne coating is done by paper converting companies that buy paper from mills and apply coatings to produce a final product. Among the many products that are coated with solventborne materials are adhesive tapes and labels, decorated paper, book covers, zinc oxide coated office copier paper, carbon paper, typewriter ribbons and photographic film.

Generally used organic solvent formulations are made up of film forming materials, plasticizers, pigments and solvents. The main classes of film formers used in paper coating are cellulose derivatives (usually nitrocellulose) and vinyl resins (usually the copolymer of vinyl chloride and vinyl acetate). Three common plasticizers are dioctyl phthalate, tricresyl phosphate and castor oil. The major solvents used are toluene, xylene, methyl ethyl ketone, isopropyl alcohol, methanol, acetone and ethanol. Although a single solvent is frequently used, a mixture is often necessary to obtain the optimum drying rate, flexibility, toughness and abrasion resistance.

A variety of low solvent coatings, with negligible emissions, has been developed for some uses to form organic resin films equal to those of conventional solventborne coatings. They can be applied up to 1/8 inch thick (usually by reverse roller coating) to products like artificial leather goods, book covers and carbon paper. Smooth hot melt finishes can be applied over rough textured paper by heated gravure or roll coaters at temperatures from 65 to 230°C (150 to 450°F).

Plastic extrusion coating is a type of hot melt coating in which a molten thermoplastic sheet (usually low or medium density polyethylene) is extruded from a slotted die at temperatures of up to 315°C (600°F). The substrate and the molten plastic coat are united by pressure between a rubber roll and a chill roll which solidifies the plastic. Many products are coated with solventless extrusion coatings, for example, the polyethylene coated milk carton.

Figure 4.2.2.6-1 shows a typical paper coating line that uses organic solventborne formulations. The application device is usually a reverse roller, a knife or a rotogravure printer. Knife coaters can apply solutions of much higher viscosity than roll coaters, thus emitting less solvent per pound of solids applied. The gravure printer can print patterns or can coat a solid sheet of color on a paper web.

Ovens may be divided into from two to five temperature zones. The first zone is usually at about 43°C (110°F) and other zones have progressively higher temperatures to cure the coating after most solvent has evaporated. The typical curing temperature is 120°C (250°F), and ovens are generally limited to 200°C (400°F) to avoid damage to the paper. Natural gas is the fuel most often used in direct fired ovens, but fuel oil is sometimes used. Some of the heavier grades of fuel oil can create problems, because SO and particulate may contaminate the paper coating. Distillate fuel oil usually can be used satisfactorily. Steam produced from burning solvent retrieved from an adsorber or vented to an incinerator may also be used to heat curing ovens.

Emissions and Controls[7] - The main emission points from paper coating lines are the coating applicator and the oven (see Figure 4.2.2.6-1). In a typical paper coating plant, about 70 percent of all solvents used are emitted from the coating lines, with most coming from the first zone of the oven. The other 30 percent are emitted from solvent transfer, storage and mixing operations and can be reduced through good housekeeping practices. All solvent used and not recovered or destroyed can be considered potential emissions.

VOC emissions from individual paper coating plants vary with size and number of coating lines, line construction, coating formulation, and substrate composition, so each must be evaluated individually. VOC emissions can be estimated from the factors in Table 4.2.2.1-1, if coating use is known and sufficient information on coating composition is available. Since many paper coating formulas are proprietary, it may be necessary to have information on the total solvent used and to assume that, unless a control device is used, essentially all solvent is emitted. Rarely would as much as 5 percent be retained in the product.

Almost all solvent emissions from the coating lines can be collected and sent to a control device. Thermal incinerators have been retrofitted to a large number of oven exhausts, with primary

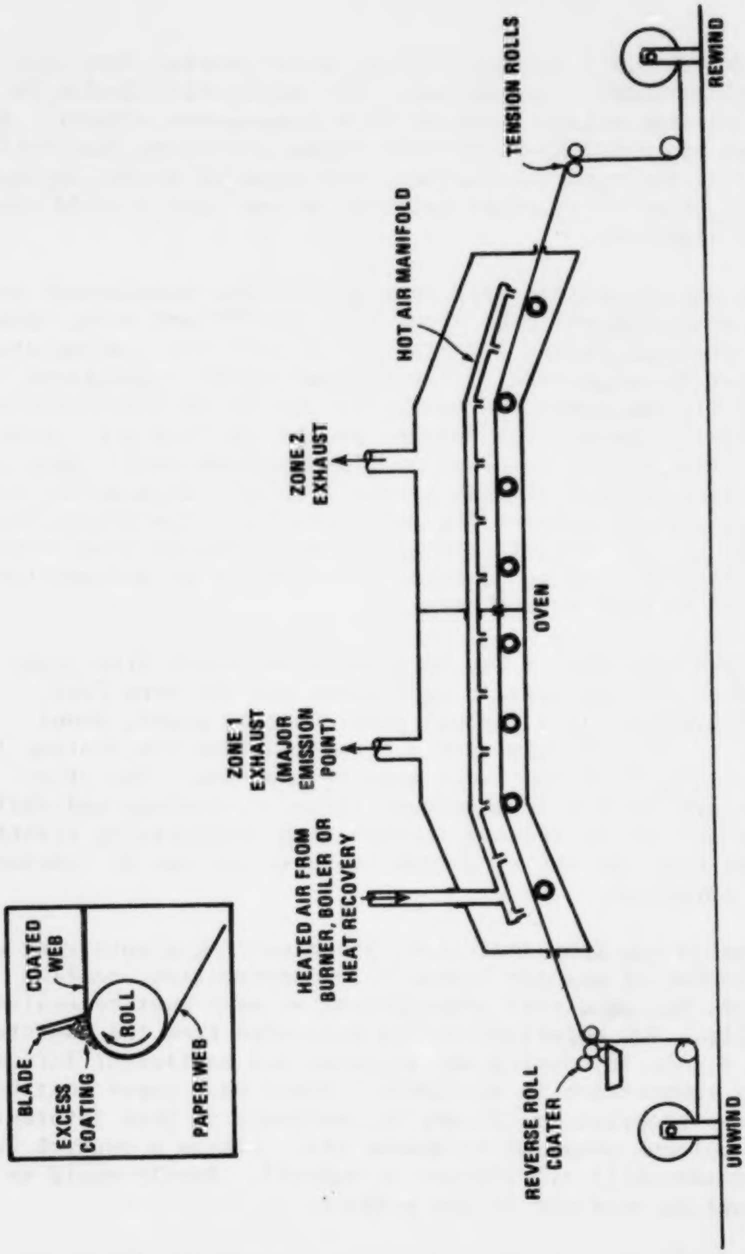
BLADE
EXCESS COATING
ROLL
COATED WEB
PAPER WEB
REVERSE ROLL COATER
UNWIND
HEATED AIR FROM BURNER, BOILER OR HEAT RECOVERY
ZONE 1 EXHAUST (MAJOR EMISSION POINT)
ZONE 2 EXHAUST
HOT AIR MANIFOLD
OVEN
TENSION ROLLS
REWIND

Figure 4.2.2.6-1. Paper coating line emission points.[7]

and even secondary heat recovery systems heating the ovens. Carbon adsorption is most easily adaptable to lines which use single solvent coating. If solvent mixtures are collected by adsorbers, they usually must be distilled for reuse.

Although available for some products, low solvent coatings are not yet available for all paper coating operations. The nature of the products, such as some types of photographic film, may preclude development of a low solvent option. Furthermore, the more complex the mixture of organic solvents in the coating, the more difficult and expensive to reclaim them for reuse with a carbon adsorption system.

Table 4.2.2.6-1 lists efficiencies of several control devices.

TABLE 4.2.2.6-1. CONTROL EFFICIENCIES FOR PAPER COATING LINES[a]

Affected Facility	Control	Efficiency (%)
Coating line	Incineration	95
	Carbon adsorption	90+
	Low solvent coating	80 - 99[b]

[a] Reference 7.

[b] Based on comparison with a conventional coating containing 35% solids and 65% organic solvent by volume.

4.2.2.7 Fabric Coating[7,15-16]

Process Description - Fabric coating imparts to a fabric substrate properties such as strength, stability, water or acid repellence, or appearance. Fabric coating is the uniform application of an elastomeric or thermoplastic polymer solution, or a vinyl plastisol or organosol, across 100 percent of at least one side of a supporting fabric surface or substrate. Coatings are applied by blade, roll coater, reverse roll coater, and in some instances, by rotogravure coater. Fabric coating should not be confused with vinyl printing and topcoating, which occurs almost exclusively on rotogravure equipment. Textile printing also should not be considered a fabric coating process.

Products usually fabric coated are rainwear, tents, tarpaulins, substrates for industrial and electrical tape, tire cord, seals and gaskets. The industry is primarily small to medium size plants, many of which are toll coaters, rather than specialists in their own product lines.

Figure 4.2.2.7-1 is of a typical fabric coating operation. If the fabric is to be coated with rubber, the rubber is milled with pigments, curing agents and fillers before being dissolved (mixed) in a suitable solvent. When other than rubber coatings are used, milling is rarely necessary.

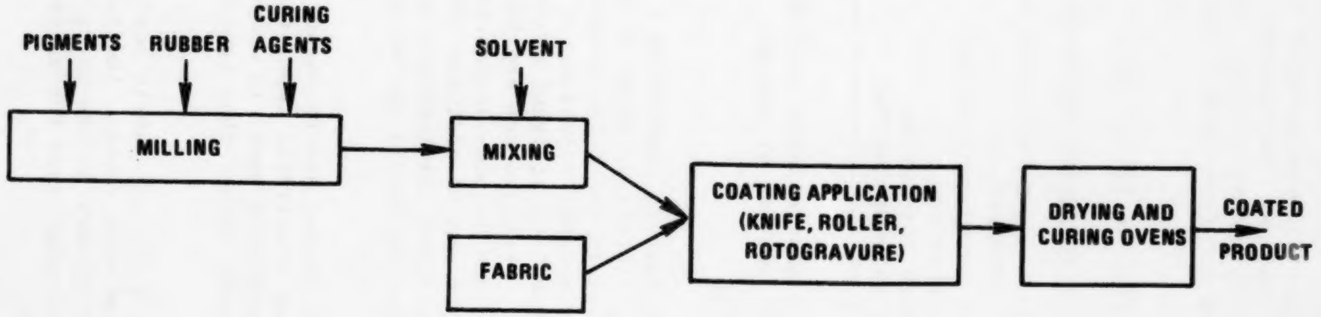
PIGMENTS
RUBBER
CURING AGENTS
MILLING
SOLVENT
MIXING
FABRIC
COATING APPLICATION (KNIFE, ROLLER, ROTOGRAVURE)
DRYING AND CURING OVENS
COATED PRODUCT

Figure 4.2.2.7-1. Fabric coating plant emission points.[7]

Emissions and Controls[7] - The VOC emissions in a fabric coating plant originate at the mixer, the coating applicator and the oven (see Figure 4.2.2.7-1). Emissions from these three areas are from 10 to 25 percent, 20 to 30 percent and 40 to 65 percent, respectively. Fugitive losses, amounting to a few percent, escape during solvent transfer, storage tank breathing, agitation of mixing tanks, waste solvent disposal, various stages of cleanup, and evaporation from the coated fabric after it leaves the line.

The most accurate method of estimating VOC emissions from a fabric coating plant is to obtain purchase or use records of all solvents in a specified time period, add to that the amount of solvent contained in purchased coating solutions, and subtract any stockpiled solvent, such as cleanup solvent, that is recovered and disposed of in a nonpolluting manner. Emissions from the actual coating line without any solvent recovery can be estimated from the factors in Table 4.2.2.1-1, if coating use is known and sufficient information on coating composition is available. Because many fabric coatings are proprietary, it may be necessary for the user to supply information on the total solvent used and to assume that, unless a control device is used, all solvent is emitted. To calculate total plant emissions, the coatings mixing losses must be accounted. These losses can be estimated from the printline losses by using the relative split of plant emissions between the mixing area and the printline. For example,

$$\text{Emissions, mixing} = \text{Emissions, printline} \left(\frac{10\% \text{ loss from mixing}}{85\% \text{ loss from printline}} \right)$$

Incineration is probably the best way to control coating application and curing emissions on coating lines using a variety of coating formulations. Primary and secondary heat recovery are likely to be used to help reduce the fuel requirements of the coating process and, therefore, to increase the economy of incineration. As with other surface coating operations, carbon adsorption is most easily accomplished by sources using a single solvent that can be recovered for reuse. Mixed solvent recovery is, however, in use in other web coating processes. Fugitive emission controls include tight covers for open tanks, collection hoods for cleanup areas, and closed containers for storage of solvent wiping cloths. Where high solids or waterborne coatings have been developed to replace conventional coatings, their use may preclude the need for a control device.

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9. *Control of Volatile Organic Emissions from Existing Stationary Sources, Volume IV: Surface Coating for Insulation of Magnet Wire*, EPA-450/2-77-033, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

10. *Controlled and Uncontrolled Emission Rates and Applicable Limitations for Eighty Processes*, EPA Contract No. 68-02-1382, TRC of New England, Wethersfield, CT, September 1976.

11. *Control of Volatile Organic Emissions from Existing Stationary Sources, Volume III: Surface Coating of Metal Furniture*, EPA-450/2-77-032, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

12. *Control of Volatile Organic Emissions from Existing Stationary Sources, Volume V: Surface Coating of Large Appliances*, EPA-450/2-77-034, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

13. *Control of Volatile Organic Emissions from Existing Stationary Sources, Volume VI: Surface Coating of Miscellaneous Metal Parts and Products*, EPA-450/2-78-015, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1978.

14. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume VII: Factory Surface Coating of Flat Wood Interior Paneling, EPA-450/2-78-032, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1978.

15. B.H. Carpenter and G.K. Hilliard, Environmental Aspects of Chemical Use in Printing Operations, EPA-560/1-75-005, U.S. Environmental Protection Agency, Washington, DC, January 1976.

16. J.C. Berry, "Fabric Printing Definition", Memorandum, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, August 25, 1980.

17. G.T. Helms, "Appropriate Transfer Efficiencies for Metal Furniture and Large Appliance Coating", Memorandum, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, November 28, 1980.

4.3 STORAGE OF ORGANIC LIQUIDS

4.3.1 Process Description

Storage vessels containing organic liquids can be found in many industries, including: (1) petroleum producing and refining, (2) petrochemical and chemical manufacturing, (3) bulk storage and transfer operations, and (4) other industries consuming or producing organic liquids. Organic liquids in the petroleum industry, usually called petroleum liquids, generally are mixtures of chemicals having dissimilar true vapor pressures (for example, gasoline and crude oil). Organic liquids in the chemical industry, usually called volatile organic liquids, are composed of pure chemicals or mixtures of chemicals with similar true vapor pressures (for example, benzene or a mixture of isopropyl and butyl alcohols).

Five basic tank designs are used for organic liquid storage vessels: fixed roof, external floating roof, internal floating roof, variable vapor space and pressure (low and high).

4.3.1.1 Fixed Roof Tanks - A typical fixed roof tank is shown in Figure 4.3-1. This type of tank consists of a cylindrical steel shell with a permanently affixed roof, which may vary in design from cone or dome shaped to flat.

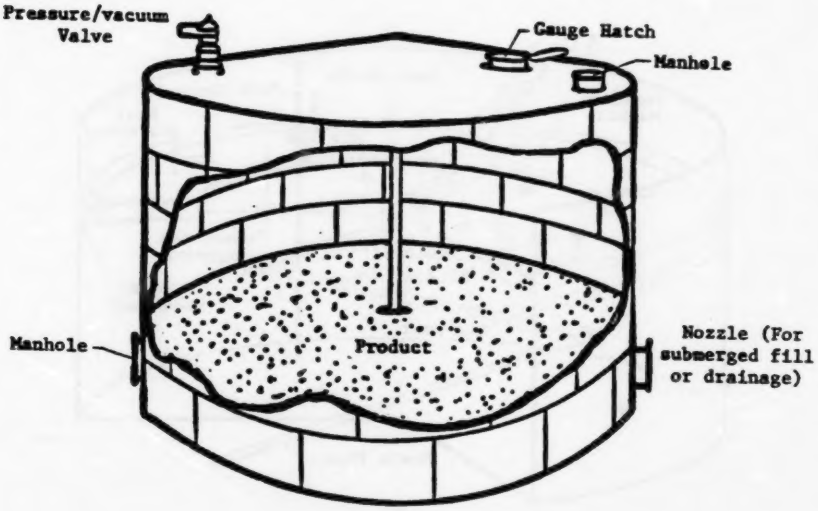

Figure 4.3-1. Typical fixed roof tank.[1]

Fixed roof tanks are commonly equipped with a pressure/vacuum vent that allows them to operate at a slight internal pressure or vacuum. The pressure/vacuum valves prevent the release of vapors only during very small changes in temperature, pressure or liquid level. These tanks are generally considered the minimum acceptable standard for storage of petroleum or volatile organic liquids with very low vapor pressures.

4.3.1.2 External Floating Roof Tanks – A typical external floating roof tank is shown in Figure 4.3-2. This type of tank consists of a cylindrical steel shell equipped with a deck or roof which floats on the surface of the stored liquid, rising and falling with the liquid level. The liquid surface is completely covered by the floating roof, except in the small annular space between the roof and the tank wall. A seal (or seal system) attached to the roof contacts the tank wall (except for small gaps, in some cases) and covers the annular space. The seal slides against the tank wall as the roof is raised or lowered. The purpose of the floating roof and the seal (or seal system) is to minimize the amount of evaporation loss of the stored liquid.

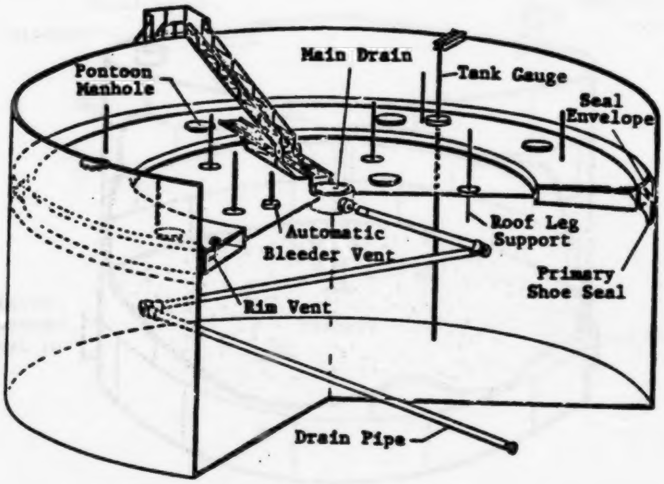

Figure 4.3-2. External floating roof tank.[2]

4.3.1.3 Internal Floating Roof Tanks - An internal floating roof tank has both a permanently affixed roof and a cover that floats on the liquid surface (contact roof), or that rests on pontoons several inches above the liquid surface (noncontact roof), inside the tank. Typical noncontact and contact internal floating roof tanks are shown in Figures 4.3-3a and 4.3-3b, respectively. The roof rises and falls with the liquid level. Contact roofs include (1) aluminum sandwich panel roofs with a honeycomb aluminum core floating in contact with the liquid, and (2) pan steel roofs floating in contact with the liquid, with or without pontoons. Noncontact roofs typically consist of an aluminum deck or an aluminum grid framework supported above the liquid surface by tubular aluminum pontoons. Both types of roof, as in the case of external floating roofs, commonly incorporate flexible perimeter seals or wipers which slide against the tank wall as the roof moves up and down. In addition, circulation vents and an open vent at the top of the fixed roof can be provided to minimize the possibility of organic vapor accumulation in concentrations approaching the flammable range.

4.3.1.4 Pressure Tanks - There are two classes of pressure tanks in general use, low pressure (2-15 psig) and high pressure (up to 250 psig or higher). Pressure tanks are generally used for storage of organic liquids with high vapor pressures and are found in many sizes and shapes, depending on the operating range of the tank. High pressure storage tanks can be operated so virtually no evaporative or working losses occur. Working losses can occur in low pressure tanks, due to atmospheric venting of the pressure tank during filling operations.

4.3.1.5 Variable Vapor Space Tanks - Variable vapor space tanks are equipped with expandable vapor reservoirs to accomodate vapor volume fluctuations attributable to temperature and barometric pressure changes. Although variable vapor space tanks are sometimes used independently, they are normally connected to the vapor spaces of one or more fixed roof tanks. The two most common types of variable vapor space tank are lifter roof tanks and flexible diaphragm tanks.

Lifter roof tanks have a telescoping roof that fits loosely around the outside of the main tank wall. The space between the roof and the wall is closed by either a wet seal, which consists of a trough filled with liquid, or a dry seal, which employs a flexible coated fabric instead of the trough.

Flexible diaphragm tanks use flexible membranes to provide expandable volume. They may be separate gasholder units or integral units mounted atop fixed roof tanks.

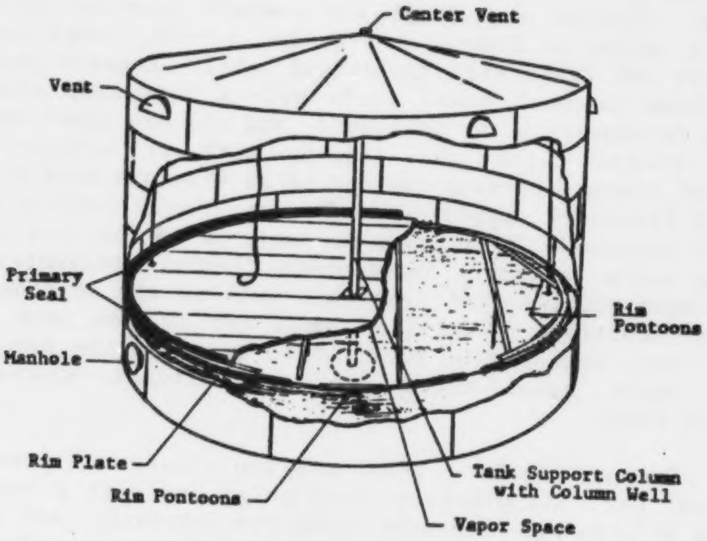
Center Vent
Vent
Primary Seal
Rim Pontoons
Manhole
Rim Plate
Rim Pontoons
Tank Support Column with Column Well
Vapor Space

Figure 4.3-3a. Noncontact internal floating roof tank.[1]

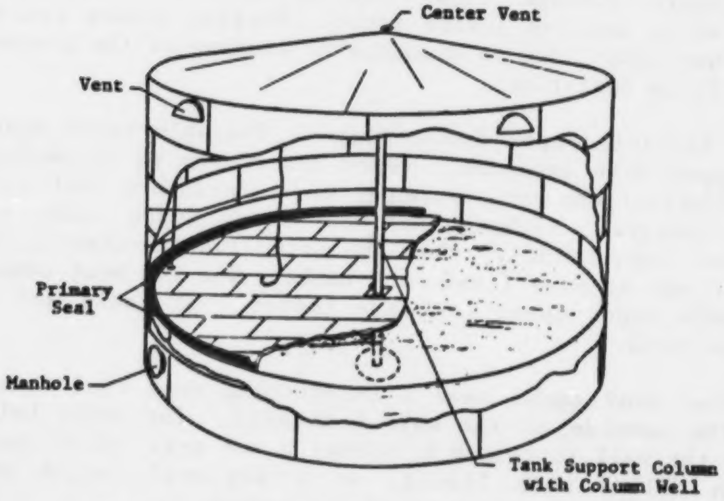
Center Vent
Vent
Primary Seal
Manhole
Tank Support Column with Column Well

Figure 4.3-3b. Contact internal floating roof tank.[1]

4.3.2 Emissions and Controls

There are six sources of emissions from organic liquids in storage: fixed roof breathing losses, fixed roof working losses, floating roof standing storage losses, floating roof withdrawal losses, variable vapor space filling losses, and pressure tank losses.

4.3.2.1 Fixed Roof Tanks - Two significant types of emissions from fixed roof tanks are breathing losses and working losses. Breathing loss is the expulsion of vapor from a tank due to vapor expansion and contraction from changes in temperature and barometric pressure. It occurs in the absence of any liquid level change in the tank.

The combined loss from filling and emptying is called working loss. Filling loss is associated with an increase of the liquid level in the tank. The vapors are expelled from the tank when the pressure inside the tank exceeds the relief pressure, as a result of filling. Emptying loss occurs when air drawn into the tank during liquid removal becomes saturated with organic vapor and expands, thus exceeding the capacity of the vapor space.

Fixed roof tank breathing losses can be estimated from[8]:

$$L_B = 2.26 \times 10^{-2} M \left(\frac{P}{14.7-P}\right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.50} F_P C K_C \quad (1)$$

where: L_B = fixed roof breathing loss (lb/year)

M = molecular weight of vapor in storage tank (lb/lb mole). See Table 4.3-1

P = true vapor pressure at bulk liquid conditions (psia). See Note 1

D = tank diameter (ft)

H = average vapor space height, including roof volume correction (ft). See Note 2

ΔT = average ambient diurnal temperature change (°F)

F_P = paint factor (dimensionless). See Table 4.3-2

C = adjustment factor for small diameter tanks (dimensionless). See Figure 4.3-4

K_C = product factor (dimensionless). See Note 3

TABLE 4.3-1. PHYSICAL PROPERTIES OF TYPICAL ORGANIC LIQUIDS[4,5]

Organic Liquid*	Vapor molecular weight @ 60°F	Product density (d), lb/gal @ 60°F	Condensed vapor density (w), lb/gal @ 60°F	True vapor pressure in psia at: 40°F	50°F	60°F	70°F	80°F	90°F	100°F
Petroleum Liquids										
Gasoline RVP 13	62	5.6	4.9	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gasoline RVP 10	66	5.6	5.1	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasoline RVP 7	68	5.6	5.2	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Crude oil RVP 5	50	7.1	4.5	1.8	2.3	2.8	3.4	4.0	4.8	5.7
Jet naphtha (JP-4)	80	6.4	5.4	0.8	1.0	1.3	1.6	1.9	2.4	2.7
Jet kerosene	130	7.0	6.1	0.0041	0.0060	0.0085	0.011	0.015	0.021	0.029
Distillate fuel No. 2	130	7.1	6.1	0.0031	0.0045	0.0064	0.0090	0.012	0.016	0.022
Residual oil No. 6	190	7.9	6.4	0.00002	0.00003	0.00004	0.00006	0.00009	0.00013	0.00019
Volatile Organic Liquids										
Acetone	58	6.6	6.6	1.7	2.2	2.9	3.7	4.7	5.9	7.3
Acrylonitrile	53	6.8	6.8	0.8	1.0	1.4	1.8	2.4	3.1	4.0
Benzene	78	7.4	7.4	0.6	0.9	1.2	1.5	2.0	2.6	3.3
Carbon disulfide	76	10.6	10.6	3.0	3.9	4.8	6.0	7.4	9.2	11.2
Carbon tetrachloride	154	13.4	13.4	0.8	1.1	1.4	1.8	2.3	3.0	3.8
Chloroform	119	12.5	12.5	1.5	1.9	2.5	3.2	4.1	5.2	6.3
Cyclohexane	84	6.5	6.5	0.7	0.9	1.2	1.6	2.1	2.6	3.2
1, 2-Dichlorethane	99	10.5	10.5	0.6	0.8	1.0	1.4	1.7	2.2	2.8
Ethylacetate	88	7.6	7.6	0.6	0.8	1.1	1.5	1.9	2.5	3.2
Ethyl alcohol	46	6.6	6.6	0.2	0.4	0.6	0.9	1.2	1.7	2.3
Isopropyl alcohol	60	6.6	6.6	0.2	0.3	0.6	0.7	0.9	1.3	1.8
Methyl alcohol	32	6.6	6.6	0.7	1.0	1.4	2.0	2.6	3.5	4.5
Methylene chloride	85	11.1	11.1	3.1	4.3	5.4	6.8	8.7	10.3	13.3
Methylethyl ketone	72	6.7	6.7	0.7	0.9	1.2	1.5	2.1	2.7	3.3
Methylmethacrylate	100	7.9	7.9	0.1	0.2	0.3	0.6	0.8	1.1	1.4
1, 1, 1-Trichloroethane	133	11.2	11.2	0.9	1.2	1.6	2.0	2.6	3.3	4.2
Trichloroethylene	131	12.3	12.3	0.5	0.7	0.9	1.2	1.5	2.0	2.0
Toluene	92	7.3	7.3	0.2	0.2	0.3	0.4	0.6	0.8	1.0
Vinylacetate	86	7.8	7.8	0.7	1.0	1.3	1.7	2.3	3.1	4.0

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[*] For a more comprehensive listing of volatile organic liquids, see Reference 4.

TABLE 4.3-2. PAINT FACTORS FOR FIXED ROOF TANKS[7]

Tank color		Paint factors (F_p)	
		Paint condition	
Roof	Shell	Good	Poor
White	White	1.00	1.15
Aluminum (specular)	White	1.04	1.18
White	Aluminum (specular)	1.16	1.24
Aluminium (specular)	Aluminum (specular)	1.20	1.29
White	Aluminum (diffuse)	1.30	1.38
Aluminum (diffuse)	Aluminum (diffuse)	1.39	1.46
White	Gray	1.30	1.38
Light gray	Light gray	1.33	1.44[a]
Medium gray	Medium gray	1.40	1.58[a]

[a] Estimated from the ratios of the seven preceding paint factors.

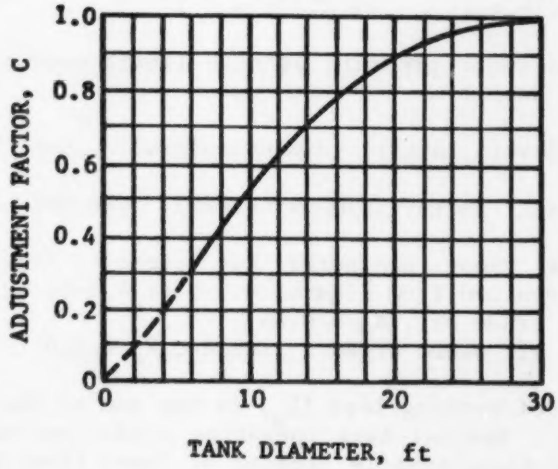


Figure 4.3-4. Adjustment factor (C) for small diameter tanks.[7]

Notes: (1) True vapor pressures for organic liquids can be determined from Figures 4.3-5 or 4.3-6, or Table 4.3-1
(2) The vapor space in a cone roof is equal in volume to a cylinder which has the same base diameter as the cone and is one third the height of the cone
(3) For crude oil, $K_C = 0.65$
For all other organic liquids, $K_C = 1.0$

Definitions

True vapor pressure: the equilibrium partial pressure exerted by a volatile organic liquid as defined by ASTM-D-2879 or as obtained from standard reference texts.

Reid vapor pressure: the absolute vapor pressure of volatile crude oil and volatile nonviscous petroleum liquids, except liquified petroleum gases, as determined by ASTM-D-323-58.

Fixed roof tank working losses can be estimated from[7]:

$$L_W = 2.40 \times 10^{-2} MPK_NK_C \qquad (2)$$

where: L_W = fixed roof working loss (lb/10^3 gal throughput)

M = molecular weight of vapor in storage tank (lb/lb mole). See Table 4.3-1

P = true vapor pressure at bulk liquid conditions (psia). See Note 1

K_N = turnover factor (dimensionless). See Figure 4.3-7

K_C = product factor (dimensionless). See Note 2

Notes: (1) True vapor pressures for organic liquids can be determined from Figures 4.3-5 or 4.3-6, or Table 4.3-1
(2) For crude oil, $K_C = 0.84$
For all other organic liquids, $K_C = 1.0$

The fixed roof working loss (L_W) is the sum of the loading and unloading losses. Special tank operating conditions may result in losses which are significantly greater or lower than the estimates provided by Equation 2.

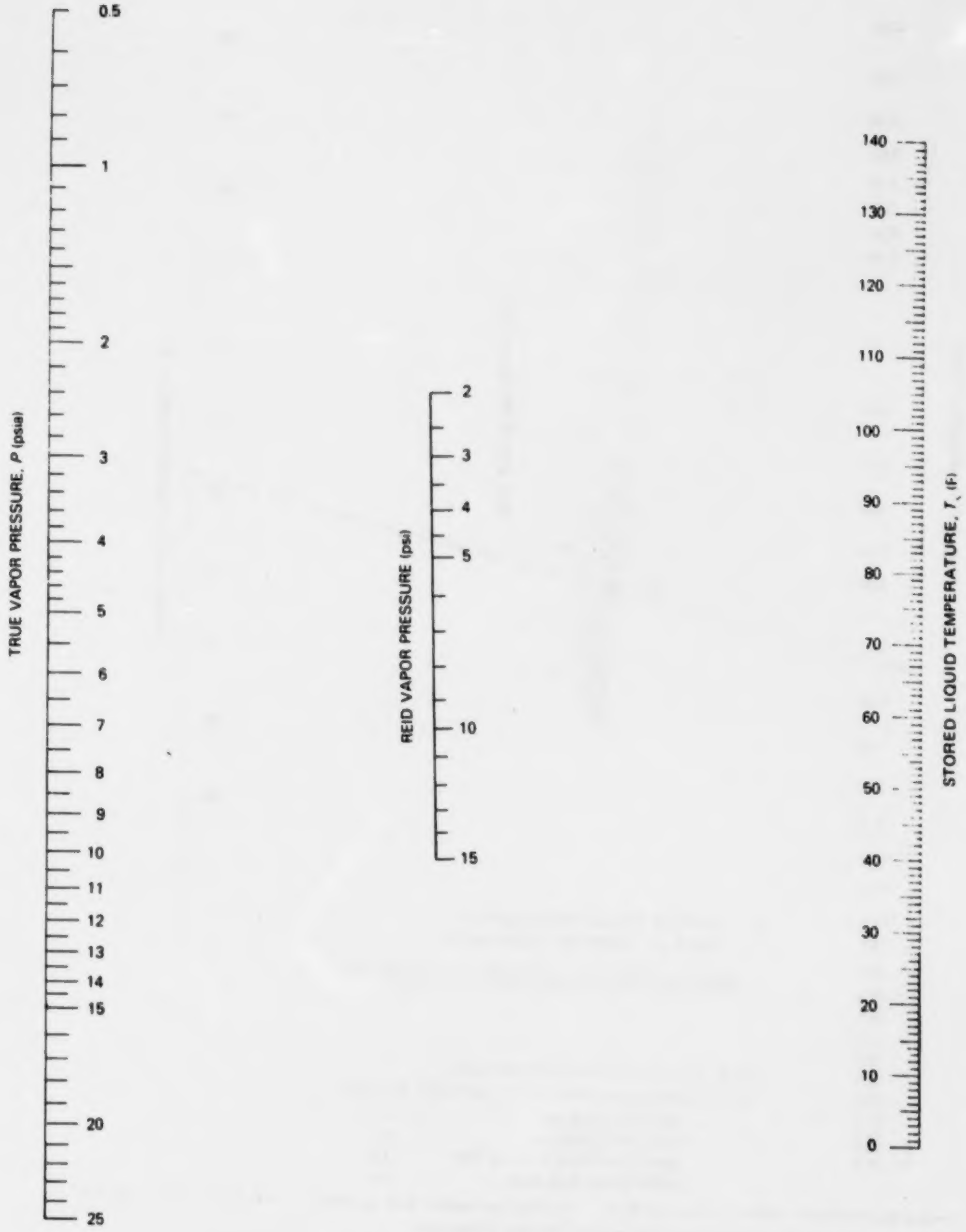
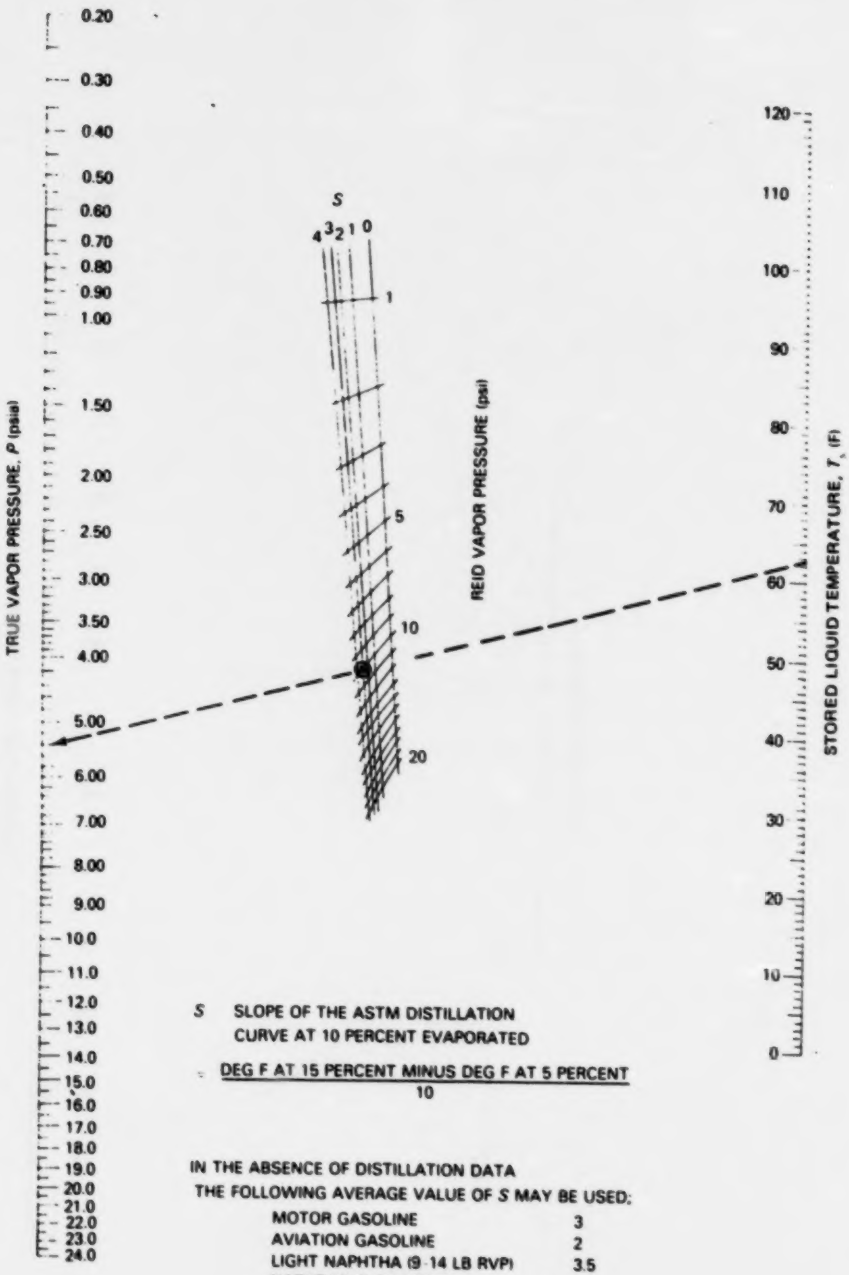


Figure 4.3-5. True vapor pressure (P) of crude oils (2-15 psi RVP).[6]



S SLOPE OF THE ASTM DISTILLATION CURVE AT 10 PERCENT EVAPORATED

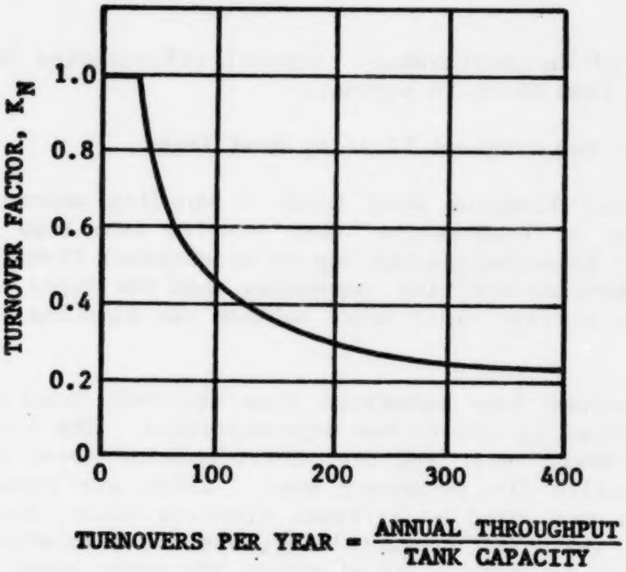
$$= \frac{\text{DEG F AT 15 PERCENT MINUS DEG F AT 5 PERCENT}}{10}$$

IN THE ABSENCE OF DISTILLATION DATA THE FOLLOWING AVERAGE VALUE OF *S* MAY BE USED:

MOTOR GASOLINE	3
AVIATION GASOLINE	2
LIGHT NAPHTHA (9-14 LB RVP)	3.5
NAPHTHA (2-8 LB RVP)	2.5

NOTE: Dashed line illustrates sample problem for RVP = 10 pounds per square inch, gasoline (S = 3), and T_s = 62.5 F.
SOURCE: Nomograph drawn from the data of the National Bureau of Standards.

Figure 4.3-6. True vapor pressure (P) of refined petroleum liquids like gasoline and naphthas (1-20 psi RVP).[6]



Note: For 36 turnovers per year or less, $K_N = 1.0$

Figure 4.3-7. Turnover factor (K_N) for fixed roof tanks.

Several methods are used to control emissions from fixed roof tanks. Emissions from fixed roof tanks can be controlled by the installation of a floating roof and seals to minimize evaporation of product being stored. The control efficiency of this method ranges from 60 to 92 percent, depending on the type of roof and seals installed and on the type of organic liquid stored.

A commonly used method, the vapor recovery system, collects emissions from storage vessels and converts them to liquid product. Several vapor recovery procedures may be used, including vapor/liquid absorption, vapor compression, vapor cooling, vapor/solid adsorption, or a combination of these. The overall control efficiencies of vapor recovery systems are as high as 90 to 98 percent, depending on the method used, the design of the unit, the composition of vapors recovered, and the mechanical condition of the system.

A further method of emission control on fixed roof tanks is thermal oxidation. In a typical thermal oxidation system, the air/vapor mixture is injected through a burner manifold into the combustion area of an incinerator. Control efficiencies for this system can range from 96 to 99 percent.

4.3.2.2 External and Internal Floating Roof Tanks

4.3.2.2.1 External Floating Roof Tanks - Standing storage loss, the major element of evaporative loss, results from wind induced mechanisms as air flows across the top of an external floating roof tank. These mechanisms may vary, depending upon the types of seals used to close the annular vapor space between the floating roof and the tank wall.

Standing storage loss emissions from external floating roof tanks are controlled by one or two separate seals. The first seal is called the primary seal, and the other, mounted above the primary seal, is called the secondary seal. There are three basic types of primary seal used on external floating roofs, mechanical (metallic shoe), resilient (nonmetallic), and flexible wiper. The resilient seal can be mounted to eliminate the vapor space between the seal and liquid surface (liquid mounted), or to allow a vapor space between the seal and liquid surface (vapor mounted). A primary seal serves as a vapor conservation device by closing the annular space between the edge of the floating roof and the tank wall. Two configurations of secondary seal are currently available, shoe mounted and rim mounted. In addition, some primary seals are protected by a metallic weather shield. Although there are other seal system designs, the systems described here comprise the majority in use today.

Withdrawal loss is another source of emissions from external floating roof tanks. This loss is the vaporization of liquid that clings to the tank wall and is exposed to the atmosphere when a floating roof is lowered by withdrawal of liquid.

4.3.2.2.2 Internal Floating Roof Tanks - Internal floating roof tanks generally have the same sources of emissions as external floating roof tanks. Standing storage and wetting losses are two sources of emissions from these tanks. Fitting losses, from penetrations in the roof by deck fittings, roof column supports, or other openings, can also account for emissions from internal floating roof tanks.

Typical internal floating roofs incorporate two types of primary seal, resilient foam filled and wiper. Similar to those employed in external floating roof tanks, these seals close the annular vapor space between the edge of the floating roof and the tank wall.

4.3.2.3 Emission Calculations for External and Internal Floating Roof Tanks: Background Information – The following equation is used to calculate standing storage loss emissions from both external floating roof and internal floating roof storage tanks:

$$L_S = K_S V^N P^* D M_V K_C E_F$$

Where: (1) L_S is the standing storage loss (lb/year)

(2) K_S and N are interdependent factors that relate the type of tank, the design of the tank seal and local wind velocity, V, to standing storage loss

(3) P^*, the vapor pressure function, is a theoretically derived function which establishes the effect of stock volatility on standing storage loss

(4) D, the tank diameter, is linear with standing storage loss as verified by field tank testing

(5) M_V, the vapor molecular weight, provides standing storage loss estimates in mass terms

(6) K_C, the product factor, establishes the relationship of standing storage loss to the type of stored organic liquid

(7) E_F, the secondary seal factor, establishes the effectiveness of secondary seals in controlling standing storage loss

The above factors were developed from emissions data obtained from field and pilot test studies conducted by oil companies, manufacturers, industry groups, and regulatory agencies, on both internal floating roof and external floating roof storage tanks. The largest set of data, concerning external floating roof tanks storing petroleum liquids, was analyzed by the American Petroleum Institute (API), and the results published in Reference 6. The K_S and N values for the primary only and primary/secondary seal systems shown in Table 4.3-3 are the same as those published in Reference 6 for seals with "average" gaps.

Due to the small amount of emissions data available for internal floating roof tanks storing volatile organic liquids and petroleum liquids, and external floating roof tanks storing volatile organic liquids, K_S and N factors for these cases were developed from correlations between those available data and the data used to develop the K_S and N values published in Reference 6. These correlations were used to develop K_S and N factors for

TABLE 4.3-3. SEAL RELATED FACTORS FOR EXTERNAL FLOATING ROOF TANKS[a,b]

Seal Type	K_S	N
Metallic Shoe Seal		
Primary seal only	1.2	1.5
With shoe mounted secondary seal	0.8	1.2
With rim mounted secondary seal	0.2	1.0
Liquid Mounted Resilient Seal		
Primary seal only	1.1	1.0
With weather shield	0.8	0.9
With rim mounted secondary seal	0.7	0.4
Vapor Mounted Resilient Seal		
Primary seal only	1.2	2.3
With weather shield	0.9	2.2
With rim mounted secondary seal	0.2	2.6

[a] Based on emissions from tank seal system with emissions control devices (roof, seals, etc.) in reasonably good working condition, no visible holes, tears or unusually large gaps between the seals and the tank wall.

[b] Factors for secondary seals are appropriate only for external floating roof tanks storing petroleum liquids.

primary seal only cases. Analysis of the available test data shows the secondary seal control efficiency to range from 55 to 93 percent. Based on this information, the secondary seal factor, E_F, was developed. For correct application of the secondary seal factor, a visual inspection of the tank and seal of interest is suggested. If the tank and seal are found in good condition (no tears or holes in the seal and no apparent large gaps at the tank wall/seal junction), a value of $E_F = 0.25$ (75 percent control efficiency) is recommended.[8]

Further analysis of all available data shows that, for any seal system, emissions from tanks storing volatile organic liquids were generally ten times those of the same tank type storing petroleum liquids. Based on this information, the value of the product factor, K_C, was determined to be 10 for tanks storing volatile organic liquids.

Due to the small amount of data available, the method and factors used to calculate standing storage loss emissions from external floating roof tanks storing volatile organic liquids, and internal floating roof tanks storing both petroleum liquids and volatile organic liquids, are considered interim methods, awaiting further data development.

4.3.2.3.1 External Floating Roof Tank Standing Storage Loss Calculations[6] – The standing storage loss from external floating roof tanks can be estimated from the following equation:

$$L_S = K_S V^N P^* D M_V K_C E_F \qquad (3)$$

Where: L_S = standing storage loss (lb/yr)

K_S = seal factor (lb-mole/(ft (mi/hr)^{N}yr)). See Note 1

V = average wind speed at tank site (mi/hr). See Note 2

N = seal related wind speed exponent (dimensionless). See Note 1

P^* = vapor pressure function (dimensionless). See Note 3

$$= \frac{\left(\frac{P}{P_A}\right)}{\left[1 + \left(1 - \frac{P}{P_A}\right)^{0.5}\right]^2}$$

P = true vapor pressure at average actual organic liquid storage temperature (psia)

P_A = average atmospheric pressure at tank location (psia)

D = tank diameter (ft)

M_V = average vapor molecular weight (lb/lb-mole). See Note 4

K_C = product factor (dimensionless). See Note 5

E_F = secondary seal factor. See Note 6

Notes: (1) For petroleum liquid storage: K_S and N for both primary only and primary/secondary seal systems are found in Table 4.3-3

For volatile organic liquid storage: only the K_S and N values of Table 4.3-3 for the primary only seal systems are employed. If the storage tank of interest has both a primary and secondary seal, use the K_S and N value for the particular primary seal of interest and the appropriate E_F value. See Note 6

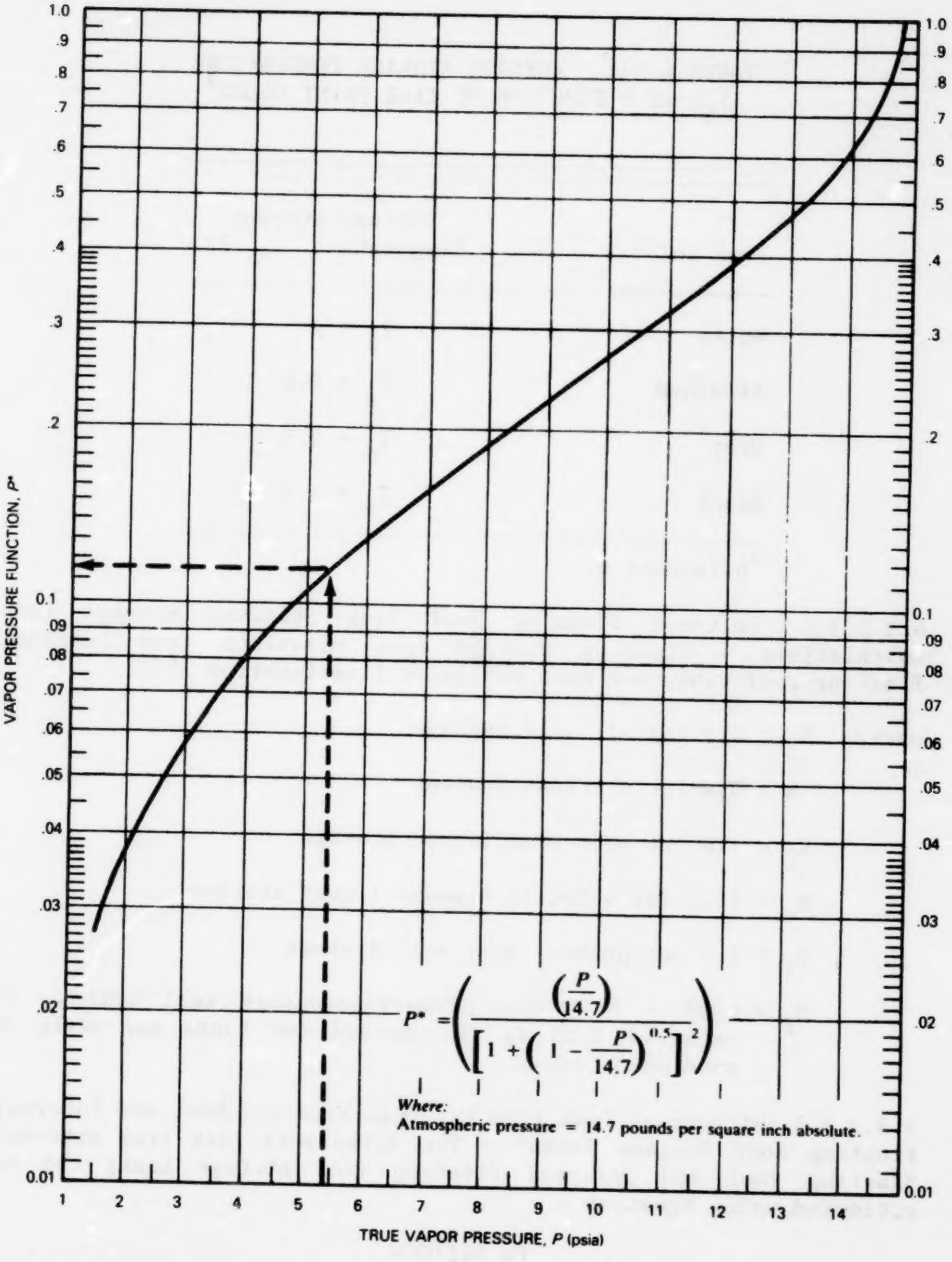
(2) If the wind speed at the tank site is not available, wind speed data from the nearest local weather station may be used as an approximation

(3) P^* can be calculated or read directly from Figure 4.3-8. True vapor pressures for organic liquids can be determined from Figures 4.3-5 or 4.3-6, or Table 4.3-1. If average actual organic liquid storage temperature, T_S, is unknown, the average storage temperature can be estimated from the average ambient temperature T_A(F) (available from local weather service data), adjusted by the tank paint color factor. See Table 4.3-4

(4) The molecular weight of the vapor, M_V, can be determined by Table 4.3-1, analysis of vapor samples, or by calculation from the liquid composition. A typical value of 64 lb/lb-mole can be assumed for gasoline, and a value of 50 lb/lb-mole can be assumed for U.S. midcontinental crude oils

(5) For all petroleum liquids except crude oil: $K_C = 1.0$
For crude oil: $K_C = 0.4$
For all volatile organic liquids: $K_C = 10.0$

(6) For petroleum liquid storage with any seal system: $E_F = 1.0$
For volatile organic liquid storage
with a primary only seal system: $E_F = 1.0$
with a primary/secondary seal system: $E_F = 0.07\text{-}0.45$
(A value of 0.25 is recommended for tanks and seals in good condition.)



$$P^* = \left(\frac{\left(\frac{P}{14.7}\right)}{\left[1 + \left(1 - \frac{P}{14.7}\right)^{0.5}\right]^2} \right)$$

Where:
Atmospheric pressure = 14.7 pounds per square inch absolute.

NOTE: Dashed line illustrates sample problem for P = 5.4 pounds per square inch absolute.

Figure 4.3-8. Vapor pressure function (P*). 6

TABLE 4.3-4. AVERAGE STORAGE TEMPERATURE (T_S) AS A FUNCTION OF TANK PAINT COLOR[a]

Tank color	Average storage Temperature, T_S (F)
White	$T_A + 0$
Aluminum	$T_A + 2.5$
Gray	$T_A + 3.5$
Black	$T_A + 5.0$

[a] Reference 6.

4.3.2.3.2 Internal Floating Roof Tank Standing Storage Loss Calculations - Standing storage loss emissions from internal floating roof tanks are best estimated from Equation 3[6,8]:

where: K_S = 0.7 for all seal systems

N = 0.4 for all seal systems

K_C = 1.0 for petroleum liquid storage

K_C = 10.0 for volatile organic liquid storage

E_F = 1.0 for primary only seal systems

E_F = 0.07 - 0.45 for primary/secondary seal systems (A value of 0.25 is recommended for tanks and seals in good condition.)

4.3.2.3.3 Withdrawal Loss from External Floating Roof and Internal Floating Roof Storage Tanks[6] - The withdrawal loss from external floating roof and internal floating roof storage tanks can be estimated using Equation 4.

$$L_W = \frac{(0.943)QCW_L}{D} \qquad (4)$$

Where: L_W = withdrawal loss (lb/yr)

Q = average throughput (barrel (bbl)/yr; 1 bbl = 42 U.S. gallons)

C = shell clingage factor (bbl/1000 ft^2). See Table 4.3-5

W_L = average organic liquid density (lb/gal). See Note 1

D = tank diameter (ft).

Notes: (1) If W_L is not known, an average value of 6.1 lbs/gallon can be assumed for gasoline. An average value cannot be assumed for crude oil, since densities are highly variable

(2) The constant, 0.943, has dimensions of (1000 ft^3 x gal/bbl^2)

4.3.2.3.4 Total Loss from External Floating Roof and Internal Floating Roof Storage Tanks[6] – The total loss from external floating roof and internal floating roof storage tanks in lb/yr can be estimated from Equation 5.

$$L_T(\text{lb/yr}) = L_S(\text{lb/yr}) + L_W(\text{lb/yr}) \qquad (5)$$

Where: L_T = total loss

L_S = standing storage loss

L_W = withdrawal loss

TABLE 4.3-5. AVERAGE CLINGAGE FACTORS (C) (bbl/1000 ft^2)[a]

Product	Shell Condition		
	Light rust	Dense rust	Gunite lined
Gasoline	0.0015	0.0075	0.15
Crude oil	0.0060	0.030	0.60

[a] Reference 6.

4.3.2.4 Pressure Tanks – Losses occur in low pressure tanks during withdrawal and filling operations when atmospheric venting occurs. High pressure tanks are considered closed systems, with virtually no emissions. Vapor recovery systems are often found on low pressure tanks. Fugitive losses are also associated with pressure tanks and their equipment, but with proper system maintenance, these losses are considered insignificant. No appropriate correlations are available for estimating vapor losses from pressure tanks.

4.3.2.5 Variable Vapor Space Tanks[3,4] – Variable vapor space filling losses result when vapor is displaced by liquid during filling operations. Since the variable vapor space tank has an expandable vapor storage capacity, this loss is not as large as the filling loss associated with fixed roof tanks. Loss of vapor occurs only when the vapor storage capacity of the tank is exceeded.

Variable vapor space system filling losses can be estimated from:

$$L_V = (2.40 \times 10^{-2}) \frac{MP}{V_1} ((V_1) - (0.25\ V_2 N)) \qquad (6)$$

Where: L_V = variable vapor space filling loss (lb/10^3 gal throughput)

M = molecular weight of vapor in storage tank (lb/lb-mole). See Table 4.3-1

P = true vapor pressure at bulk liquid conditions (psia). See Note 1

V_1 = volume of liquid pumped into system; throughput (bbl)

V_2 = volume expansion capacity of system (bbl). See Note 2

N = number of transfers into system (dimensionless). See Note 3

Notes: (1) True vapor pressure for organic liquids can be determined from Figures 4.3-5 or 4.3-6, or Table 4.3-1

(2) V_2 is the volume expansion capacity of the variable vapor space achieved by roof lifting or diaphragm flexing

(3) N is the number of transfers into the system during the time period that corresponds to a throughput of V_1

The accuracy of Equation 6 is not documented. Special tank operating conditions may result in actual losses which are significantly different from the estimates provided by Equation 6. It should also be noted that, although not developed for use with heavier petroleum liquids such as kerosenes and fuel oils, the equation is recommended for use with heavier petroleum liquids in the absence of better data.

Vapor recovery systems capture organic vapors displaced during filling operations and recover the organic vapors by refrigeration, absorption, adsorption and/or compression. Control efficiencies range from 90 to 98 percent, depending on the nature of the vapors and on the recovery equipment used.

4.3.3 Sample Calculations –

4.3.3.1 Problem I: Estimate the total standing storage loss for 3 months based on data observed during the months of March, April and May, given the following information:

Tank description:	External floating roof tank with a mechanical shoe primary seal in good condition; 100 ft. diameter; tank shell painted aluminum color.
Stored product:	Motor gasoline (petroleum liquid); Reid vapor pressure, 10 psia; 6.1 lb/gal liquid density; no vapor or liquid composition given; 375,000 bbl throughput for the 3 months.
Ambient conditions:	60°F average ambient temperature for the 3 months; 10 mi/hr average wind speed at tank site for the 3 months; assume 14.7 psia atmospheric pressure.

Standing Storage Loss – Calculate the yearly standing storage loss from Equation 3.

$$L_S(\text{lb/yr}) = K_S V^N P^* D M_V K_C E_F \qquad (3)$$

The variables in Equation 3 can be determined as follows:

K_S = 1.2 (from Table 4.3-3, for a welded tank with a mechanical shoe primary seal)

N = 1.5 (from Table 4.3-3, for a welded tank with a mechanical shoe primary seal)

V = 10 mi/hr (given)

$V^N = (10)^{1.5} = 32$

T_A = 60°F (given)

T_S = 62.5°F (from Table 4.3-4, for an aluminum color tank in good condition and T_A = 60°F)

RVP = 10 psia (given)

P = 5.4 psia (from Figure 4.3-6, for 10 psia Reid vapor pressure gasoline and T_S = 62.5°F)

P_A = 14.7 psia (assumed)

$$P^* = \frac{\left(\frac{5.4}{14.7}\right)}{\left[1 + \left(1 - \frac{5.4}{14.7}\right)^{0.5}\right]^2} = 0.114$$

(from Equation 3 or from Figure 4.3-8 for P = 5.4 psia)

D = 100 ft (given)

M_V = 64 lb/lb-mole (assumed for gasoline)

K_C = 1.0 (for an external floating roof storage tank storing a petroleum liquid)

E_F = 1.0 (for an external floating roof storage tank storing a petroleum liquid)

To calculate yearly standing storage loss, based on the 3 month data, multiply the K_S, V^N, P^*, D, M_V, K_C, and E_F values, as in Equation 3. To calculate emissions for time intervals other than 1 year, a yearly standing storage loss must be initially calculated and the resulting emissions scaled according to the desired time interval.

$$\begin{aligned} L_S(\text{lb/yr}) &= (1.2)(32)(0.114)(100)(64)(1.0)(1.0) \\ &= 28{,}016 \text{ lb/yr} \end{aligned}$$

To calculate the standing storage loss for the 3 months, divide L_S in (lb/yr) by 4 (3 months is 1/4 of a year).

$$L_S = \frac{(28{,}016)}{4} = 7004 \text{ lbs for 3 months}$$

Withdrawal Loss - Calculate the withdrawal loss from Equation 4.

$$L_W(\text{lb/yr}) = (0.943)\ \frac{QCW_1}{D} \tag{4}$$

The variables in Equation 4 can be determined as follows:

$Q = 3.75 \times 10^5$ bbl for 3 months = 1.5×10^6 bbl/yr (given)

$C = 0.0015$ bbl/1000 ft^2 (from Table 4.3-5, for gasoline in a steel tank with light rust)

$W_L = 6.1$ lb/gal (given)

$D = 100$ ft (given)

To calculate yearly withdrawal loss, use Equation 4.

$$L_W(\text{lb/yr}) = \frac{(0.943)(1.5 \times 10^6)(0.0015)(6.1)}{100} \tag{4}$$

$$= 129 \text{ lb/yr}$$

To calculate withdrawal loss for 3 months, divide by 4.

$$L_W = 129/4 = 32 \text{ lbs for 3 months}$$

Total Loss - Calculate the total loss in (lb/yr) from Equation 5.

$$L_T(\text{lb/yr}) = L_S(\text{lb/yr}) + L_W(\text{lb/yr}) \tag{5}$$

$$L_T(\text{lb/yr}) = (28{,}016) + (129) = 28{,}145 \text{ lb/yr}$$

To calculate the total loss for 3 months, divide by 4.

$$L_T = \frac{28{,}145}{4} = 7036 \text{ lbs for 3 months}$$

4.3.3.2 Problem II: Estimate the yearly standing storage loss from an external floating roof tank storing a volatile organic liquid (excluding withdrawal loss) given the following information:

Tank description same as in Problem I, except the tank now is equipped with a mechanical shoe seal and a secondary seal.

Stored product: Benzene.

Ambient Conditions: Same as in Problem I.

Standing Storage Loss –

$$L_S(\text{lb/yr}) = K_S V^N P^* D M_V K_C E_F \qquad (3)$$

The variables in Equation 3 are the same as in Problem I, with the following exceptions:

P = 1.2 psia (from Table 4.3-1 for benzene at 60°F)

P_A = 14.7 psia (assumed)

$$P^* = \frac{\left(\frac{1.2}{14.7}\right)}{\left[1 \;+\; 1 - \left(\frac{1.2}{14.7}\right)^{.5}\right]^2} = 0.021$$

M_V = 78 lb/lb-mole (from Table 4.3-1)

K_C = 10 (given for calculation of volatile organic liquid emissions from external floating roof tanks)

E_F = .25 (for tank and seals in good condition)

To calculate the yearly standing storage loss, multiply the K_S, V^N, P^*, D, M_V, K_C, and E_F values as in Equation 3.

$$\begin{aligned} L_S(\text{lb/yr}) &= (1.2)(32)(0.021)(100)(78)(10)(.25) \\ &= 15{,}725 \text{ lb/yr} \end{aligned}$$

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2. Control of Volatile Organic Emissions from Petroleum Liquid Storage in External Floating Roof Tanks, EPA-450/2-78-047, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1978.

3. Use of Variable Vapor Space Systems To Reduce Evaporation Loss, Bulletin No. 2520, American Petroleum Institute, New York, NY, 1964.

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5. Henry C. Barnett, et al., Properties of Aircraft Fuels, NACA-TN 3276, Lewis Flight Propulsion Laboratory, Cleveland, OH, August 1956.

6. Evaporation Loss from External Floating Roof Tanks, Bulletin No. 2517, American Petroleum Institute, Washington, DC, 1980.

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4.6 SOLVENT DEGREASING

4.6.1 General[1,2]

Solvent degreasing (or solvent cleaning) is the physical process of using organic solvents to remove grease, fats, oils, wax or soil from various metal, glass or plastic items. The types of equipment used in this method are categorized as cold cleaners, open top vapor degreasers, or conveyorized degreasers. Nonaqueous solvents such as petroleum distillates, chlorinated hydrocarbons, ketones and alcohols are used. Solvent selection is based on the solubility of the substance to be removed and on the toxicity, flammability, flash point, evaporation rate, boiling point, cost and several other properties of the solvent.

The metalworking industries are the major users of solvent degreasing, i.e., automotive, electronics, plumbing, aircraft, refrigeration and business machine industries. Solvent cleaning is also used in industries such as printing, chemicals, plastics, rubber, textiles, glass, paper and electric power. Most repair stations for transportation vehicles and electric tools use solvent cleaning at least part of the time. Many industries use water based alkaline wash systems for degreasing, and since these systems emit no solvent vapors to the atmosphere, they are not included in this discussion.

Cold Cleaners - The two basic types of cold cleaners are maintenance and manufacturing. Cold cleaners are batch loaded, nonboiling solvent degreasers, usually providing the simplest and least expensive method of metal cleaning. Maintenance cold cleaners are smaller, more numerous and generally using petroleum solvents as mineral spirits (petroleum distillates and Stoddard solvents). Manufacturing cold cleaners use a wide variety of solvents, which perform more specialized and higher quality cleaning with about twice the average emission rate of maintenance cold cleaners. Some cold cleaners can serve both purposes.

Cold cleaner operations include spraying, brushing, flushing and immersion. In a typical maintenance cleaner (Figure 4.6-1), dirty parts are cleaned manually by spraying and then soaking in the tank. After cleaning, the parts are either suspended over the tank to drain or are placed on an external rack that routes the drained solvent back into the cleaner. The cover is intended to be closed whenever parts are not being handled in the cleaner. Typical manufacturing cold cleaners vary widely in design, but there are two basic tank designs, the simple spray sink and the dip tank. Of these, the dip tank provides more thorough cleaning through immersion, and often is made to improve cleaning efficiency by agitation. Small cold cleaning operations may be numerous in urban areas. However, because of the small quantity of emissions from each operation, the large number of individual sources within an urban area, and the application of small cold cleaning to industrial

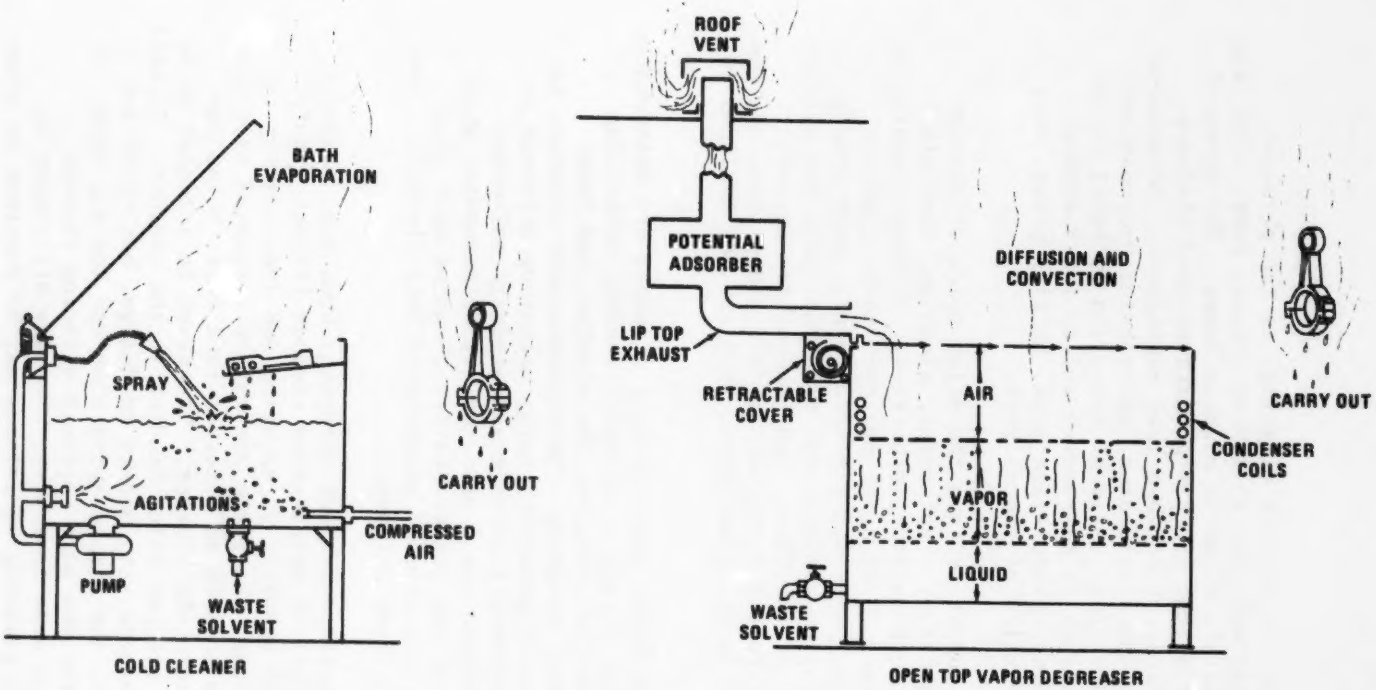
BATH EVAPORATION
SPRAY
AGITATIONS
CARRY OUT
COMPRESSED AIR
PUMP
WASTE SOLVENT
COLD CLEANER
ROOF VENT
POTENTIAL ADSORBER
LIP TOP EXHAUST
RETRACTABLE COVER
DIFFUSION AND CONVECTION
AIR
VAPOR
LIQUID
CONDENSER COILS
CARRY OUT
WASTE SOLVENT
OPEN TOP VAPOR DEGREASER

Figure 4.6-1. Degreaser emission points.

uses not directly associated with degreasing, it is difficult to identify individual small cold cleaning operations. For these reasons, factors are provided in Table 4.6-1 to estimate emissions from small cold cleaning operations over large urban geographical areas. Factors in Table 4.6-1 are for nonmethane VOC and include 25 percent 1,1,1 - trichloroethane, methylene chloride and trichlorotrifluoroethane.

TABLE 4.6-1. NONMETHANE VOC EMISSIONS FROM SMALL COLD CLEANING DEGREASING OPERATIONS[a]

EMISSION FACTOR RATING: C

Operating period	Per capita emission factor
Annual	1.8 kg 4.0 lb
Diurnal	5.8 g 0.013 lb

[a] Reference 3.

[b] Assumes a 6 day operating week (313 days/yr).

Open Top Vapor Systems - Open top vapor degreasers are batch loaded boiling degreasers that clean with condensation of hot solvent vapor on colder metal parts. Vapor degreasing uses halogenated solvents (usually perchloroethylene, trichloroethylene, or 1,1,1-trichloroethane), because they are not flammable and their vapors are much heavier than air.

A typical vapor degreaser (Figure 4.6-1) is a sump containing a heater that boils the solvent to generate vapors. The height of these pure vapors is controlled by condenser coils and/or a water jacket encircling the device. Solvent and moisture condensed on the coils are directed to a water separator, where the heavier solvent is drawn off the bottom and is returned to the vapor degreaser. A "freeboard" extends above the top of the vapor zone to minimize vapor escape. Parts to be cleaned are immersed in the vapor zone, and condensation continues until they are heated to the vapor temperature. Residual liquid solvent on the parts rapidly evaporates as they are slowly removed from the vapor zone. Lip mounted exhaust systems carry solvent vapors away from operating personnel. Cleaning action is often increased by spraying the parts with solvent below the vapor level or by immersing them in the liquid solvent bath. Nearly all vapor degreasers are equipped with a water separator which allows the solvent to flow back into the degreaser.

Emission rates are usually estimated from solvent consumption data for the particular degreasing operation under consideration.

Solvents are often purchased specifically for use in degreasing and are not used in any other plant operations. In these cases, purchase records provide the necessary information, and an emission factor of 1,000 kg of volatile organic emissions per metric ton of solvent purchased can be applied, based on the assumption that all solvent purchased is eventually emitted. When information on solvent consumption is not available, emission rates can be estimated if the number and type of degreasing units are known. The factors in Table 4.6-2 are based on the number of degreasers and emissions produced nationwide and may be considerably in error when applied to one particular unit.

The expected effectiveness of various control devices and procedures is listed in Table 4.6-3. As a first approximation, this efficiency can be applied without regard for the specific solvent being used. However, efficiencies are generally higher for more volatile solvents. These solvents also result in higher emission rates than those computed from the "average" factors listed in Table 4.6-2.

Conveyorized Degreasers - Conveyorized degreasers may operate with either cold or vaporized solvent, but they merit separate consideration because they are continuously loaded and are almost always hooded or enclosed. About 85 percent are vapor types, and 15 percent are nonboiling.

4.6.2 Emissions and Controls[1-3]

Emissions from cold cleaners occur through (1) waste solvent evaporation, (2) solvent carryout (evaporation from wet parts), (3) solvent bath evaporation, (4) spray evaporation, and (5) agitation (Figure 4.6-1). Waste solvent loss, cold cleaning's greatest emission source, can be reduced through distillation and transport of waste solvent to special incineration plants. Draining cleaned parts for at least 15 seconds reduces carryout emissions. Bath evaporation can be controlled by using a cover regularly, by allowing an adequate freeboard height and by avoiding excessive drafts in the workshop. If the solvent used is insoluble in, and heavier than, water, a layer of water two to four inches thick covering the halogenated solvent can also reduce bath evaporation. This is known as a "water cover". Spraying at low pressure also helps to reduce solvent loss from this part of the process. Agitation emissions can be controlled by using a cover, by agitating no longer than necessary, and by avoiding the use of agitation with low volatility solvents. Emissions of low volatility solvents increase significantly with agitation. However, contrary to what one might expect, agitation causes only a small increase in emissions of high volatility solvents. Solvent type is the variable which most affects cold cleaner emission rates, particularly the volatility at operating temperatures.

TABLE 4.6-2. SOLVENT LOSS EMISSION FACTORS FOR DEGREASING OPERATIONS

EMISSION FACTOR RATING: C

Type of degreasing	Activity measure	Uncontrolled organic emission factor[a]	
All[b]	Solvent consumed	1,000 kg/Mg	2,000 lb/ton
Cold cleaner			
Entire unit[c]	Units in operation	0.30 Mg/yr/unit	0.33 tons/yr/unit
Waste solvent loss		0.165 Mg/yr/unit	0.18 tons/yr/unit
Solvent carryout		0.075 Mg/yr/unit	0.08 tons/yr/unit
Bath and spray evaporation		0.06 Mg/yr/unit	0.07 tons/yr/unit
Entire unit	Surface area and duty cycle[d]	0.4 kg/hr/m^2	0.08 lb/hr/ft^2
Open top vapor			
Entire unit	Units in operation	9.5 Mg/yr/unit	10.5 tons/yr/unit
Entire unit	Surface area and duty cycle[e]	0.7 kg/hr/m^2	0.15 lb/hr/ft^2
Conveyorized, vapor			
Entire unit	Units in operation	24 Mg/yr/unit	26 tons/yr/unit
Conveyorized, nonboiling			
Entire unit	Units in operation	47 Mg/yr/unit	52 tons/yr/unit

[a] 100% nonmethane VOC.

[b] Solvent consumption data will provide much more accurate emission estimates than any of the other factors presented.

[c] Emissions generally would be higher for manufacturing units and lower for maintenance units.

[d] Reference 4, Appendix C-6. For trichloroethane degreaser.

[e] For trichloroethane degreaser. Does not include waste solvent losses.

TABLE 4.6-3. PROJECTED EMISSION REDUCTION FACTORS FOR SOLVENT DEGREASING[a]

System	Cold cleaner		Vapor degreaser		Conveyorized degreaser	
	A	B	A	B	A	B
Control devices						
Cover or enclosed design	X	X	X	X	X	X
Drainage facility	X	X	X			X
Water cover, refrigerated chiller, carbon adsorption or high freeboard[b]		X		X		X
Solid, fluid spray stream[c]		X		X		
Safety switches and thermostats				X		X
Emission reduction from control devices (%)	13-38	NA[d]	20-40	30-60		40-60
Operating procedures						
Proper use of equipment	X	X	X	X	X	X
Use of high volatility solvent		X				
Waste solvent reclamation	X	X	X	X	X	X
Reduced exhaust ventilation			X	X	X	X
Reduced conveyor or entry speed			X	X	X	X
Emission reduction from operating procedures(%)	15-45	NA[d]	15-35	20-40	20-30	20-30
Total emission reduction(%)	28-83[e]	55-69[f]	30-60	45-75	20-30	50-70

[a] Reference 2. Ranges of emission reduction present poor to excellent compliance. X indicates devices or procedures which will effect the given reductions. Letters A and B indicate different control device circumstances. See Appendix B of Reference 2.

[b] Only one of these major control devices would be used in any degreasing system. System B could employ any of them. Vapor degreaser system B could employ any except water cover. Conveyorized degreaser system B could employ any except water cover and high freeboard.

[c] If agitation by spraying is used, the spray should not be a shower type.

[d] Breakout between control equipment and operating procedures is not available.

[e] A manual or mechanically assisted cover would contribute 6-18% reduction; draining parts 15 seconds within the degreaser, 7-20%; and storing waste solvent in containers, an additional 15-45%.

[f] Percentages represent average compliance.

As with cold cleaning, open top vapor degreasing emissions relate heavily to proper operating methods. Most emissions are due to (6) diffusion and convection, which can be reduced by using an automated cover, by using a manual cover regularly, by spraying below the vapor level, by optimizing work loads or by using a refrigerated freeboard chiller (for which a carbon adsorption unit would be substituted on larger units). Safety switches and thermostats that prevent emissions during malfunctions and abnormal operation also reduce diffusion and convection of the vaporized solvent. Additional sources are (7) solvent carryout, (8) exhaust systems and (9) waste solvent evaporation. Carryout is directly affected by the size and shape of the workload, by racking of parts and by cleaning and drying time. Exhaust emissions can be nearly eliminated by a carbon adsorber that collects the solvent vapors for reuse. Waste solvent evaporation is not so much a problem with vapor degreasers as it is with cold cleaners, because the halogenated solvents used are often distilled and recycled by solvent recovery systems.

Because of their large workload capacity and the fact that they are usually enclosed, conveyorized degreasers emit less solvent per part cleaned than do either of the other two types of degreaser. More so than operating practices, design and adjustment are major factors affecting emissions, the main source of which is carryout of vapor and liquid solvents.

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4.9 GRAPHIC ARTS

4.9.1 General

Process Description - The term "graphic arts" as used here means four basic processes of the printing industry: web offset lithography, web letterpress, rotogravure and flexography. Screen printing and manual and sheet fed techniques are not included in this discussion.

Printing may be performed on coated or uncoated paper and on other surfaces, as in metal decorating and some fabric coating (see Section 4.2, Industrial Surface Coating). The material to receive the printing is called the substrate. The distinction between printing and paper coating, which may employ rotogravure or lithographic methods, is that printing invariably involves the application of ink by a printing press. However, printing and paper coating have these elements in common: application of a relatively high solvent content material to the surface of a moving web or film, rapid solvent evaporation by movement of heated air across the wet surface, and solvent laden air exhausted from the system.

Printing inks vary widely in composition, but all consist of three major components: pigments, which produce the desired colors and are composed of finely divided organic and inorganic materials; binders, the solid components that lock the pigments to the substrate and are composed of organic resins and polymers or, in some inks, oils and rosins; and solvents, which dissolve or disperse the pigments and binders and are usually composed of organic compounds. The binder and solvent make up the "vehicle" part of the ink. The solvent evaporates from the ink into the atmosphere during the drying process.

Web Offset Lithography - Lithography, the process used to produce about 75 percent of books and pamphlets and an increasing number of newspapers, is characterized by a planographic image carrier (i.e., the image and nonimage areas are on the same plane). The image area is ink wettable and water repellant, and the nonimage area is chemically repellant to ink. The solution used to dampen the plate may contain 15 to 30 percent isopropanol, if the Dalgren dampening system is used.[8] When the image is applied to a rubber covered "blanket" cylinder and then transferred onto the substrate, the process is known as "offset" lithography. When a web (i.e., a continuous roll) of paper is employed with the offset process, this is known as web offset printing. Figure 4.9-1 illustrates a web offset lithography publication printing line. A web newspaper printing line contains no dryer, because the ink contains very little solvent, and somewhat porous paper is generally used.

Web offset employs "heatset" (i.e., heat drying offset) inks that dry very quickly. For publication work the inks contain about 40 percent solvent, and for newspaper work 5 percent solvent is used. In both cases, the solvents are usually petroleum derived

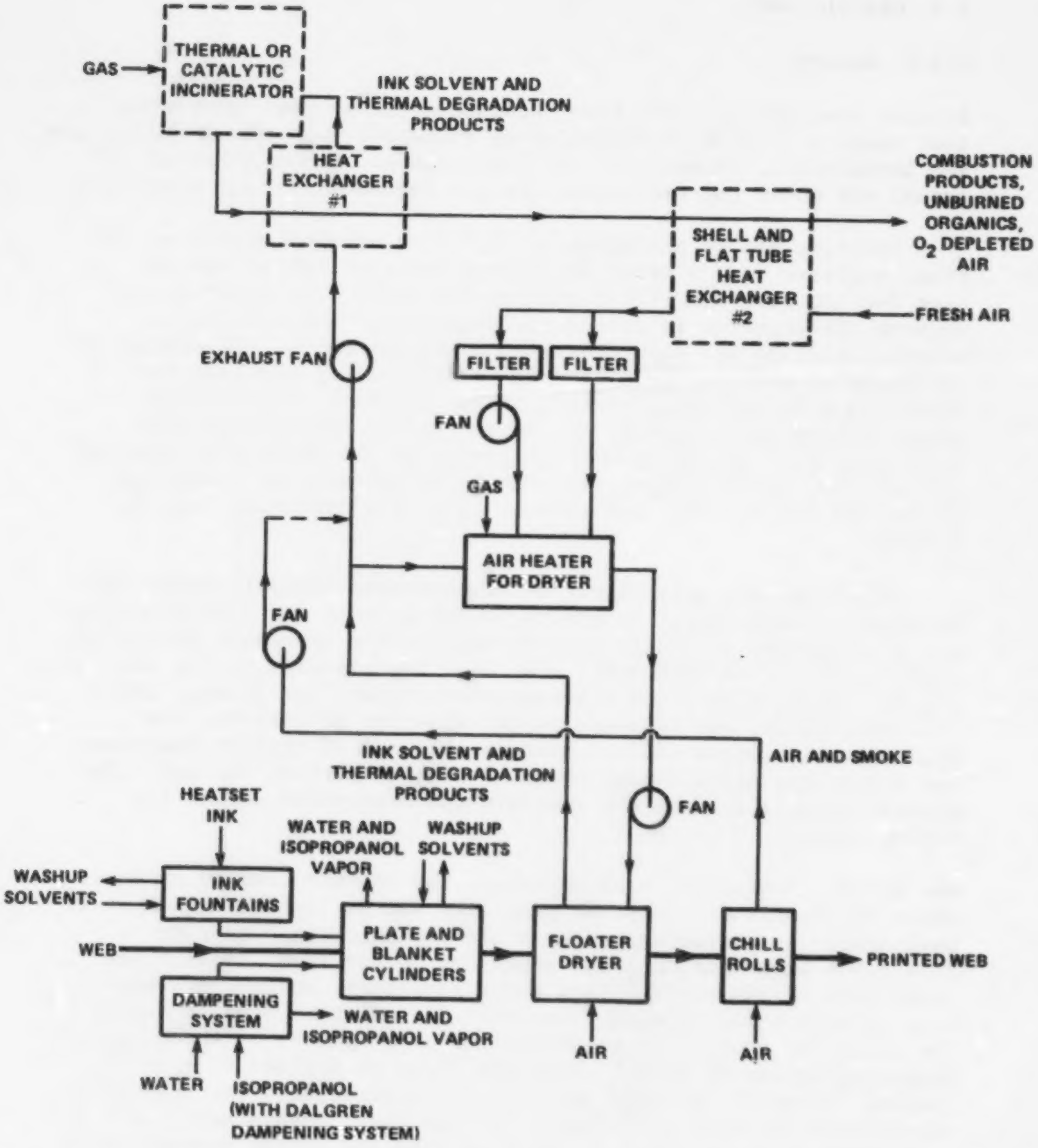
GAS
THERMAL OR CATALYTIC INCINERATOR
INK SOLVENT AND THERMAL DEGRADATION PRODUCTS
HEAT EXCHANGER #1
COMBUSTION PRODUCTS, UNBURNED ORGANICS, O2 DEPLETED AIR
SHELL AND FLAT TUBE HEAT EXCHANGER #2
FRESH AIR
EXHAUST FAN
FILTER
FILTER
FAN
GAS
AIR HEATER FOR DRYER
FAN
INK SOLVENT AND THERMAL DEGRADATION PRODUCTS
AIR AND SMOKE
FAN
HEATSET INK
WASHUP SOLVENTS
INK FOUNTAINS
WATER AND ISOPROPANOL VAPOR
WASHUP SOLVENTS
WEB
PLATE AND BLANKET CYLINDERS
FLOATER DRYER
CHILL ROLLS
PRINTED WEB
DAMPENING SYSTEM
WATER AND ISOPROPANOL VAPOR
AIR
AIR
WATER
ISOPROPANOL (WITH DALGREN DAMPENING SYSTEM)

Figure 4.9-1. Web offset lithography publication printing line emission points.[11]

hydrocarbons. In a publication web offset process, the web is printed on both sides simultaneously and passed through a tunnel or floater dryer at about 200-290°C (400-500°F). The dryer may be hot air or direct flame. Approximately 40 percent of the incoming solvent remains in the ink film, and more may be thermally degraded in a direct flame dryer. The web passes over chill rolls before folding and cutting. In newspaper work no dryer is used, and most of the solvent is believed to remain in the ink film on the paper.[11]

Web Letterpress - Letterpress is the oldest form of moveable type printing, and it still dominates in periodical and newspaper publishing, although numerous major newspapers are converting to web offset. In letterpress printing, the image area is raised, and the ink is transferred to the paper directly from the image surface. The image carrier may be made of metal or plastic. Only web presses using solventborne inks are discussed here. Letterpress newspaper and sheet fed printing use oxidative drying inks, not a source of volatile organic emissions. Figure 4.9-2 shows one unit of a web publication letterpress line.

Publication letterpress printing uses a paper web that is printed on one side at a time and dried after each color is applied. The inks employed are heatset, usually of about 40 volume percent solvent. The solvent in high speed operations is generally a selected petroleum fraction akin to kerosene and fuel oil, with a boiling point of 200-370°C (400-700°F).[13]

Rotogravure - In gravure printing, the image area is engraved, or "intaglio" relative to the surface of the image carrier, which is a copper plated steel cylinder that is usually also chrome plated to enhance wear resistance. The gravure cylinder rotates in an ink trough or fountain. The ink is picked up in the engraved area, and ink is scraped off the nonimage area with a steel "doctor blade". The image is transferred directly to the web when it is pressed against the cylinder by a rubber covered impression roll, and the product is then dried. Rotary gravure (web fed) systems are known as "rotogravure" presses.

Rotogravure can produce illustrations with excellent color control, and it may be used on coated or uncoated paper, film, foil and almost every other type of substrate. Its use is concentrated in publications and advertising such as newspaper supplements, magazines and mail order catalogues; folding cartons and other flexible packaging materials; and specialty products such as wall and floor coverings, decorated household paper products and vinyl upholstery. Figure 4.9-3 illustrates one unit of a publication rotogravure press. Multiple units are required for printing multiple colors.

The inks used in rotogravure publication printing contain from 55 to 95 volume percent low boiling solvent (average is 75 volume percent), and they must have low viscosities. Typical gravure

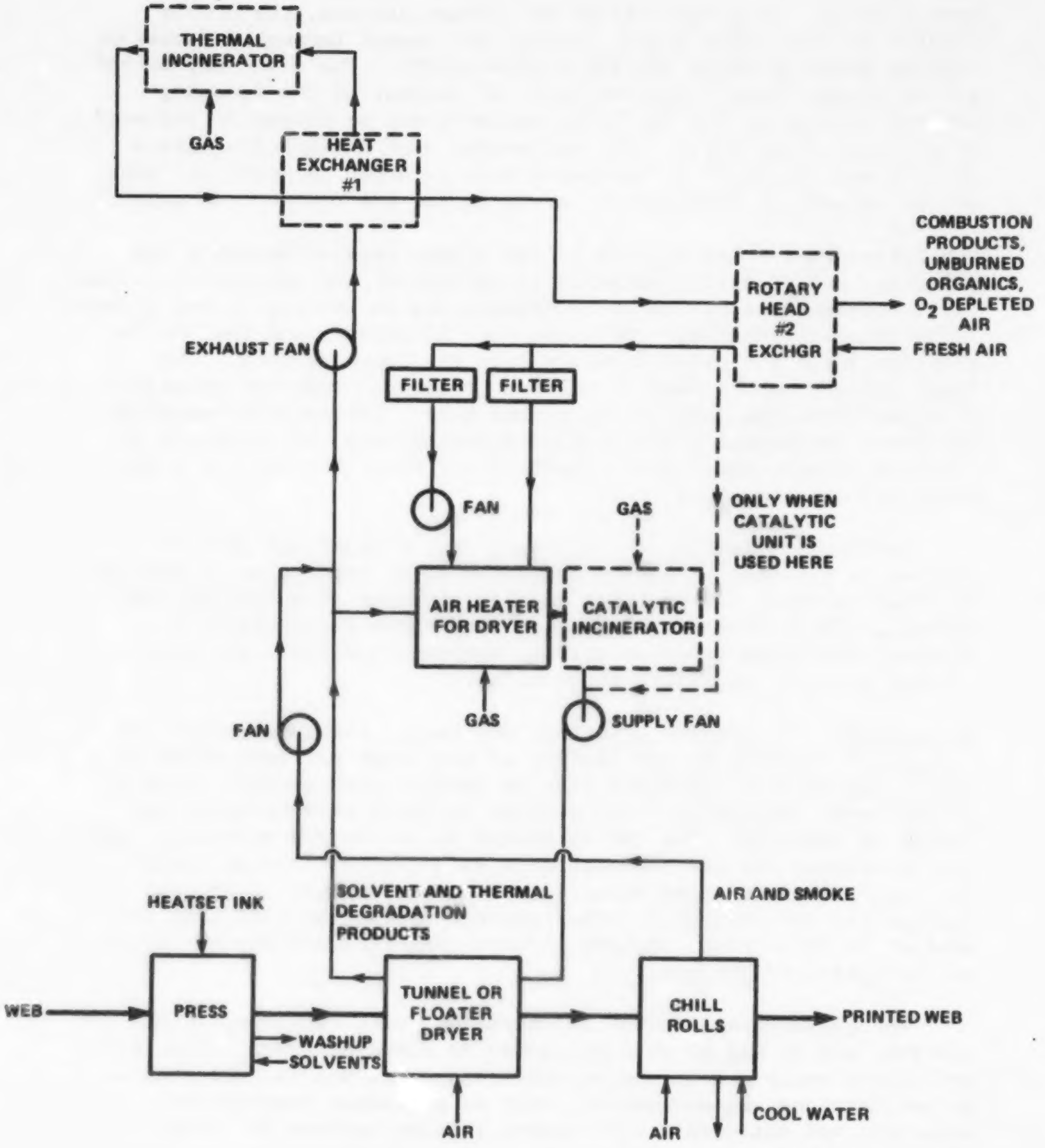
THERMAL INCINERATOR
GAS
HEAT EXCHANGER #1
COMBUSTION PRODUCTS, UNBURNED ORGANICS, O_2 DEPLETED AIR
ROTARY HEAD #2 EXCHGR
FRESH AIR
EXHAUST FAN
FILTER
FILTER
FAN
GAS
ONLY WHEN CATALYTIC UNIT IS USED HERE
AIR HEATER FOR DRYER
CATALYTIC INCINERATOR
FAN
GAS
SUPPLY FAN
HEATSET INK
SOLVENT AND THERMAL DEGRADATION PRODUCTS
AIR AND SMOKE
WEB
PRESS
WASHUP SOLVENTS
TUNNEL OR FLOATER DRYER
CHILL ROLLS
PRINTED WEB
AIR
AIR
COOL WATER

Figure 4.9-2. Web letterpress publication printing line emission points.[11]

solvents include alcohols, aliphatic naphthas, aromatic hydrocarbons, esters, glycol ethers, ketones and nitroparaffins. Water base inks are in regular production use in some packaging and specialty applications, such as sugar bags.

Rotogravure is similar to letterpress printing in that the web is printed on one side at a time and must be dried after application of each color. Thus, for four color, two sided publication printing, eight presses are employed, each including a pass over a steam drum or through a hot air dryer at temperatures from ambient up to 120°C (250°F) where nearly all of the solvent is removed.[3] For further information, see Section 4.9.2.

Flexography - In flexographic printing, as in letterpress, the image area is above the surface of the plate. The distinction is that flexography uses a rubber image carrier and alcohol base inks. The process is usually web fed and is employed for medium or long multicolor runs on a variety of substrates, including heavy paper, fiberboard and metal and plastic foil. The major categories of the flexography market are flexible packaging and laminates, multiwall bags, milk cartons, gift wrap, folding cartons, corrugated paperboard (which is sheet fed), paper cups and plates, labels, tapes and envelopes. Almost all milk cartons and multiwall bags and half of all flexible packaging are printed by this process.

Steam set inks, employed in the "water flexo" or "steam set flexo" process, are low viscosity inks of a paste consistency that are gelled by water or steam. Steam set inks are used for paper bag printing, and they produce no significant emissions. Water base inks, usually pigmented suspensions in water, are also available for some flexographic operations, such as the printing of multiwall bags.

Solvent base inks are used primarily in publication printing, as shown in Figure 4.9-3. As with rotogravure, flexography publication printing uses very fluid inks of about 75 volume percent organic solvent. The solvent, which must be rubber compatible, may be alcohol, or alcohol mixed with an aliphatic hydrocarbon or ester. Typical solvents also include glycols, ketones and ethers. The inks dry by solvent absorption into the web and by evaporation, usually in high velocity steam drum or hot air dryers, at temperatures below 120°C (250°F).[3,13] As in letterpress publishing, the web is printed on only one side at a time. The web passes over chill rolls after drying.

Emissions and Controls - Significant emissions from printing operations consist primarily of volatile organic solvents. Such emissions vary with printing process, ink formulation and coverage, press size and speed, and operating time. The type of paper (coated or uncoated) has little effect on the quantity of emissions, although low levels of organic emissions are derived from the paper stock

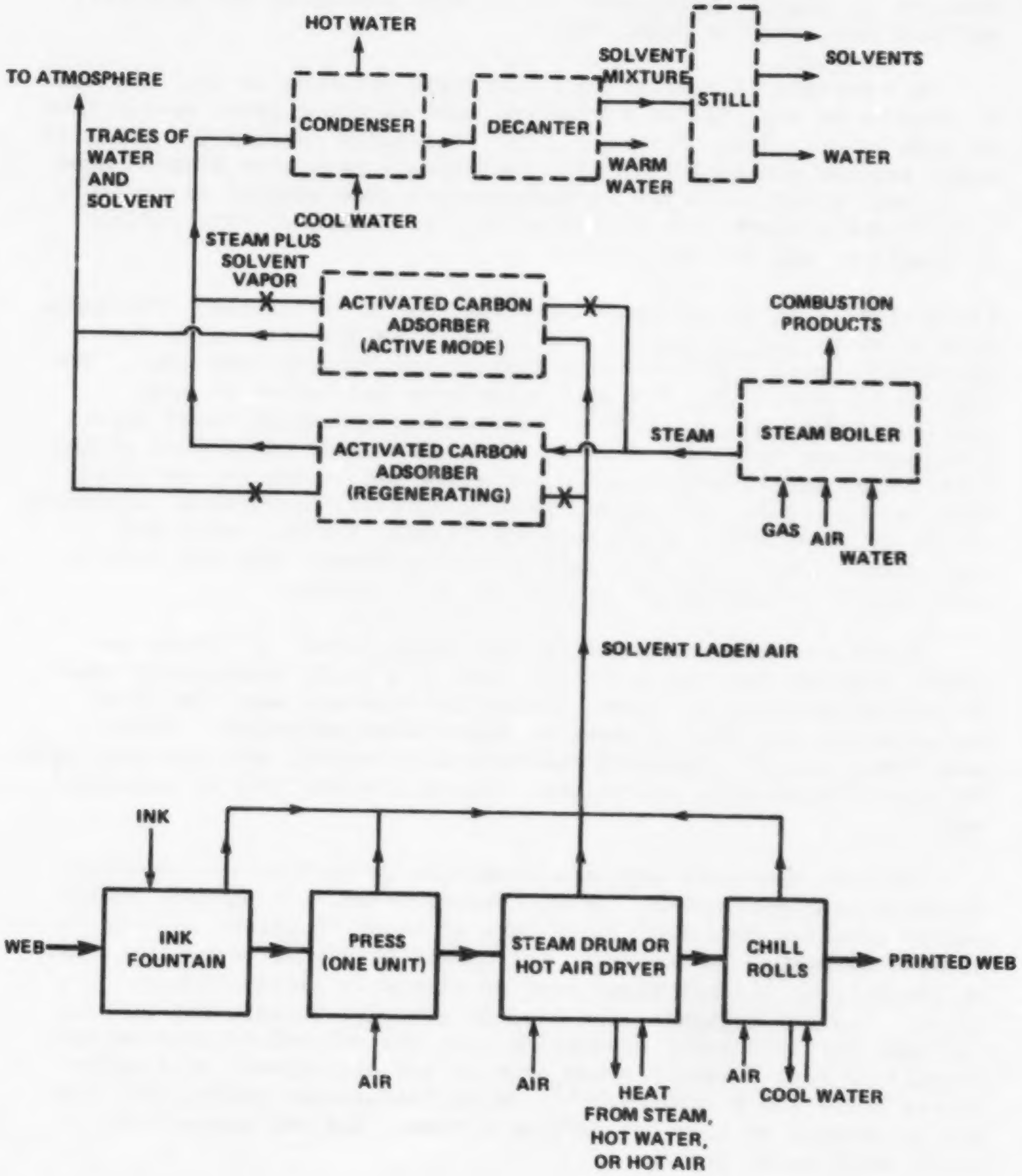
HOT WATER
TO ATMOSPHERE
SOLVENT MIXTURE
SOLVENTS
CONDENSER
DECANTER
STILL
TRACES OF WATER AND SOLVENT
WARM WATER
WATER
COOL WATER
STEAM PLUS SOLVENT VAPOR
ACTIVATED CARBON ADSORBER (ACTIVE MODE)
COMBUSTION PRODUCTS
STEAM
STEAM BOILER
ACTIVATED CARBON ADSORBER (REGENERATING)
GAS
AIR
WATER
SOLVENT LADEN AIR
INK
WEB
INK FOUNTAIN
PRESS (ONE UNIT)
STEAM DRUM OR HOT AIR DRYER
CHILL ROLLS
PRINTED WEB
AIR
AIR
HEAT FROM STEAM, HOT WATER, OR HOT AIR
AIR
COOL WATER

Figure 4.9-3. Rotogravure and flexography printing line emission points (chill rolls not used in rotogravure publication printing).[11]

during drying.[13] High volume web fed presses such as those discussed above are the principal sources of solvent vapors. Total annual emissions from the industry in 1977 were estimated to be 380,000 Mg (418,000 tons). Of this total, lithography emits 28 percent, letterpress 18 percent, gravure 41 percent and flexography 13 percent.[3]

Most of the solvent contained in the ink and used for dampening and cleanup eventually finds its way into the atmosphere, but some solvent remains with the printed product leaving the plant and is released to the atmosphere later. Overall solvent emissions can be computed from Equation 1 using a material balance concept, except in cases where a direct flame dryer is used and some of the solvent is thermally degraded.

The density of naphtha base solvent at 21°C (70°F) is 6.2 pounds per gallon.

$$E_{total} = T \qquad (1)$$

where

E_{total} = total solvent emissions including those from the printed product, kg (lb)

T = total solvent use including solvent contained in ink as used, kg (lb)

The solvent emissions from the dryer and other printline components can be computed from Equation 2. The remaining solvent leaves the plant with the printed product and/or is degraded in the dryer.

$$E = \frac{ISd}{100} \; \frac{(100 - P)}{100} \qquad (2)$$

where

E = solvent emissions from printline, kg (lb)

I = ink use, liters (gallons)

d = solvent density, kg/liter (lb/gallon)

S and P = factors from Table 4.9-1

Per Capita Emission Factors - Although major sources contribute most of the emissions for graphic arts operations, considerable emissions also originate from minor graphic arts applications, including inhouse printing services in general industries. Small sources within the graphic arts industry are numerous and difficult to identify, since many applications are associated with nonprinting

TABLE 4.9-1. TYPICAL PARAMETERS FOR COMPUTING SOLVENT EMISSIONS FROM PRINTING LINES[a,b]

Process	Solvent Content of Ink (Volume %) [S]	Solvent Remaining in Product and Destroyed in Dryer (%) [P][c]	Emission Factor Rating
Web Offset			
Publication	40	40 (hot air dryer) 60 (direct flame dryer)	B
Newspaper	5	100	B
Web Letterpress			
Publication	40	40	B
Newspaper	0	(not applicable)	
Rotogravure	75	2 - 7	C
Flexography	75	2 - 7	C

[a] References 1 and 14.

[b] Values for S and P are typical. Specific values for S and P should be obtained from a source to estimate its emissions.

[c] For certain packaging products, amount of solvent retained is regulated by FDA.

TABLE 4.9-2. PER CAPITA NONMETHANE VOC EMISSION FACTORS FOR SMALL GRAPHIC ARTS APPLICATIONS

EMISSION FACTOR RATING: D

Units	Emission Factor[a]
kg/year/capita	0.4
lb/year/capita	0.8
g/day/capita	1
lb/day/capita	0.003

[a] Reference 15. All nonmethane VOC.

[b] Assumes a 6 day operating week (313 days/yr).

industries. Table 4.9-2 presents per capita factors for estimating emissions from small graphic arts operations. The factors are entirely nonmethane VOC and should be used for emission estimates over broad geographical areas.

Web Offset Lithography - Emission points on web offset lithography publication printing lines include (1) the ink fountains, (2) the dampening system, (3) the plate and blanket cylinders, (4) the dryer, (5) the chill rolls and (6) the product (see Figure 4.9-1).

Alcohol is emitted from Points 2 and 3. Washup solvents are a small source of emissions from Points 1 and 3. Drying (Point 4) is the major source, because 40 to 60 percent of the ink solvent is removed from the web during this process.

The quantity of web offset emissions may be estimated from Equation 1, or from Equation 2 and the appropriate data from Table 4.9-1.

Web Letterpress - Emission points on web letterpress publication printing lines are: the press (includes the image carrier and inking mechanism), the dryer, the chill rolls and the product (see Figure 4.9-2).

Web letterpress publication printing produces significant emissions, primarily from the ink solvent, about 60 percent of which is lost in the drying process. Washup solvents are a small source of emissions. The quantity of emissions can be computed as described for web offset.

Letterpress publication printing uses a variety of papers and inks that lead to emission control problems, but losses can be reduced by a thermal or catalytic incinerator, either of which may be coupled with a heat exchanger.

Rotogravure - Emissions from rotogravure printing occur at the ink fountain, the press, the dryer and the chill rolls (see Figure 4.9-3). The dryer is the major emission point, because most of the VOC in the low boiling ink is removed during drying. The quantity of emissions can be computed from Equation 1, or from Equation 2 and the appropriate parameters from Table 4.9-1.

Vapor capture systems are necessary to minimize fugitive solvent vapor loss around the ink fountain and at the chill rolls. Fume incinerators and carbon adsorbers are the only devices that have a high efficiency in controlling vapors from rotogravure operations.

Solvent recovery by carbon adsorption systems has been quite successful at a number of large publication rotogravure plants. These presses use a single water immiscible solvent (toluene) or a simple mixture that can be recovered in approximately the proportions used in the ink. All new publication gravure plants are being designed to include solvent recovery.

Some smaller rotogravure operations, such as those that print and coat packaging materials, use complex solvent mixtures in which many of the solvents are water soluble. Thermal incineration with heat recovery is usually the most feasible control for such operations.

TABLE 4.9-3. ESTIMATED CONTROL TECHNOLOGY EFFICIENCIES FOR PRINTING LINES

Method	Application	Reduction in Organic Emissions (%)
Carbon adsorption	Publication rotogravure operations	75[a]
Incineration[b]	Web offset lithography	95[c]
	Web letterpress	95[d]
	Packaging rotogravure printing operations	65[a]
	Flexography printing operations	60[a]
Waterborne inks[e]	Some packaging rotogravure printing operations[f]	65-75[a]
	Some flexography packaging printing operations	60[a]

[a] Reference 3. Overall emission reduction efficiency (capture efficiency multiplied by control device efficiency).

[b] Direct flame (thermal) catalytic and pebble bed. Three or more pebble beds in a system have a heat recovery efficiency of 85%.

[c] Reference 12. Efficiency of volatile organic removal - does not consider capture efficiency.

[d] Reference 13. Efficiency of volatile organic removal - does not consider capture efficiency.

[e] Solvent portion consists of 75 volume % water and 25 volume % organic solvent.

[f] With less demanding quality requirements.

With adequate primary and secondary heat recovery, the amount of fuel required to operate both the incinerator and the dryer system can be reduced to less than that normally required to operate the dryer alone.

In addition to thermal and catalytic incinerators, pebble bed incinerators are also available. Pebble bed incinerators combine the functions of a heat exchanger and a combustion device, and can achieve a heat recovery efficiency of 85 percent.

VOC emissions can also be reduced by using low solvent inks. Waterborne inks, in which the volatile portion contains up to 20 volume percent water soluble organic compounds, are used extensively in rotogravure printing of multiwall bags, corrugated paperboard and other packaging products, although water absorption into the paper limits the amount of waterborne ink that can be printed on thin stock before the web is seriously weakened.

Flexography - Emission points on flexographic printing lines are the ink fountain, the press, the dryer and the chill rolls (see Figure 4.9-3). The dryer is the major emission point, and emissions can be estimated from Equation 1, or from Equation 2 and the appropriate parameters from Table 4.9-1.

Vapor capture systems are necessary to minimize fugitive solvent vapor loss around the ink fountain and at the chill rolls. Fume incinerators are the only devices proven highly efficient in controlling vapors from flexographic operations. VOC emissions can also be reduced by using waterborne inks, which are used extensively in flexographic printing of packaging products.

Table 4.9-3 shows estimated control efficiencies for printing operations.

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4.9.2 PUBLICATION GRAVURE PRINTING

Process Description[1,2] - Publication gravure printing is the printing by the rotogravure process of a variety of paper products such as magazines, catalogs, newspaper supplements and preprinted inserts, and advertisements. Publication printing is the largest sector involved in gravure printing, representing over 37 percent of the total gravure product sales value in a 1976 study.

The rotogravure press is designed to operate as a continuous printing facility, and normal operation may be either continuous or nearly so. Normal press operation experiences numerous shutdowns caused by web breaks or mechanical problems. Each rotogravure press generally consists of eight to sixteen individual printing units, with an eight unit press the most common. In publication printing, only four colors of ink are used, yellow, red, blue and black. Each unit prints one ink color on one side of the web, and colors other than these four are produced by printing one color over another to yield the desired product.

In the rotogravure printing process, a web or substrate from a continuous roll is passed over the image surface of a revolving gravure cylinder. For publication printing, only paper webs are used. The printing images are formed by many tiny recesses or cells etched or engraved into the surface of the gravure cylinder. The cylinder is about one fourth submerged in a fountain of low viscosity mixed ink. Raw ink is solvent diluted at the press and is sometimes mixed with related coatings, usually referred to as extenders or varnishes. The ink, as applied, is a mixture of pigments, binders, varnish and solvent. The mixed ink is picked up by the cells on the revolving cylinder surface and is continuously applied to the paper web. After impression is made, the web travels through an enclosed heated air dryer to evaporate the volatile solvent. The web is then guided along a series of rollers to the next printing unit. Figure 4.9.2-1 illustrates this printing process by an end (or side) view of a single printing unit.

At present, only solventborne inks are used on a large scale for publication printing. Waterborne inks are still in research and development stages, but some are now being used in a few limited cases. Pigments, binders and varnishes are the nonvolatile solid components of the mixed ink. For publication printing, only aliphatic and aromatic organic liquids are used as solvents. Presently, two basic types of solvents, toluene and a toluene-xylene-naphtha mixture, are used. The naphtha base solvent is the more common. Benzene is present in both solvent types as an impurity, in concentrations up to about 0.3 volume percent. Raw inks, as purchased, have 40 to 60 volume percent solvent, and the related coatings typically contain about 60 to 80 volume percent solvent. The applied mixed ink consists of 75 to 80 volume percent solvent, required to achieve the proper fluidity for rotogravure printing.

Emissions and Controls[1,3-4] - Volatile organic compound (VOC) vapors are the only significant air pollutant emissions from publication rotogravure printing. Emissions from the printing presses depend on the total amount of solvent used. The sources of these VOC emissions are the solvent components in the raw inks, related coatings used at the printing presses, and solvent added for dilution and press cleaning. These solvent organics are photochemically reactive. VOC emissions from both controlled and uncontrolled publication rotogravure facilities in 1977 were about 57,000 megagrams (63,000 tons), 15 percent of the total from the graphic arts industry. Emissions from ink and solvent storage and transfer facilities are not considered here.

Table 4.9-1 presents emission factors for publication printing on rotogravure presses with and without control equipment. The potential amount of VOC emissions from the press is equal to the total amount of solvent consumed in the printing process (see Footnote f). For uncontrolled presses, emissions occur from the dryer exhaust vents, printing fugitive vapors, and evaporation of solvent retained in the printed product. About 75 to 90 percent of the VOC emissions occur from the dryer exhausts, depending on press operating speed, press shutdown frequency, ink and solvent composition, product printed, and dryer designs and efficiencies. The amount of solvent retained by the various rotogravure printed products is three to four percent of the total solvent in the ink used. The retained solvent eventually evaporates after the printed product leaves the press.

There are numerous points around the printing press from which fugitive emissions occur. Most of the fugitive vapors result from solvent evaporation in the ink fountain, exposed parts of the gravure cylinder, the paper path at the dryer inlet, and from the paper web after exiting the dryers between printing units. The quantity of fugitive vapors depends on the solvent volatility, the temperature of the ink and solvent in the ink fountain, the amount of exposed area around the press, dryer designs and efficiencies, and the frequency of press shutdowns.

The complete air pollution control system for a modern publication rotogravure printing facility consists of two sections, the solvent vapor capture system and the emission control device. The capture system collects VOC vapors emitted from the presses and directs them to a control device where they are either recovered or destroyed. Low-VOC waterborne ink systems to replace a significant amount of solventborne inks have not been developed as an emission reduction alternative.

Capture Systems - Presently, only the concentrated dryer exhausts are captured at most facilities. The dryer exhausts contain the majority of the VOC vapors emitted. The capture efficiency of dryers is limited by their operating temperatures and

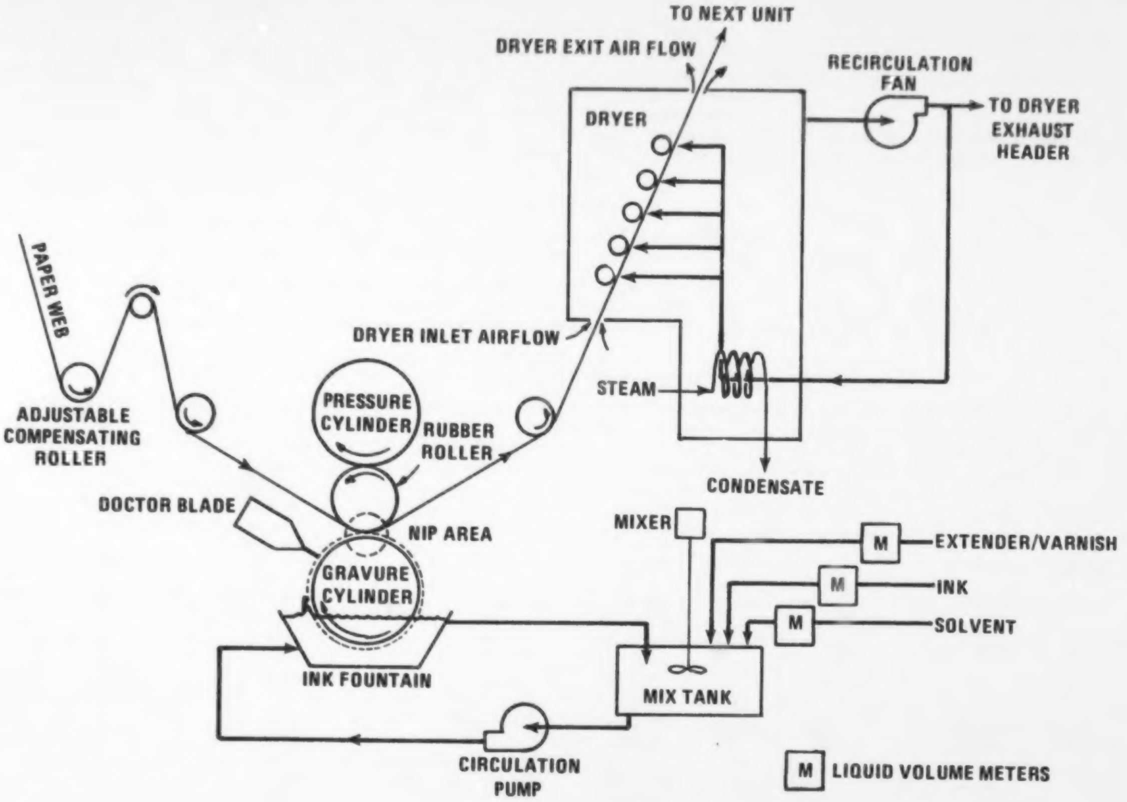
TO NEXT UNIT
DRYER EXIT AIR FLOW
RECIRCULATION FAN
TO DRYER EXHAUST HEADER
DRYER
PAPER WEB
DRYER INLET AIRFLOW
STEAM
ADJUSTABLE COMPENSATING ROLLER
PRESSURE CYLINDER
RUBBER ROLLER
CONDENSATE
DOCTOR BLADE
NIP AREA
MIXER
M
EXTENDER/VARNISH
INK
SOLVENT
GRAVURE CYLINDER
INK FOUNTAIN
MIX TANK
CIRCULATION PUMP
M LIQUID VOLUME METERS

Figure 4.9.2-1. Diagram of a rotogravure printing unit.

Table 4.9.2-1. EMISSION FACTORS FOR PUBLICATION ROTOGRAVURE PRINTING PRESSES

EMISSION FACTOR RATING: C

	VOC Emissions[a]								
	Uncontrolled			75% Control			85% Control		
	Total solvent	Raw ink		Total solvent	Raw ink		Total solvent	Raw ink	
Emission Points	kg/kg (lb/lb)	kg/liter	lb/gal	kg/kg (lb/lb)	kg/liter	lb/gal	kg/kg (lb/lb)	kg/liter	lb/gal
Dryer exhausts[b]	0.84	1.24	10.42	-	-	-	-	-	-
Fugitives[c]	0.13	0.19	1.61	0.13	0.19	1.61	0.07	0.10	0.87
Printed product[d]	0.03	0.05	0.37	0.03	0.05	0.37	0.03	0.05	0.37
Control device[e]	-	-	-	0.09	0.13	1.12	0.05	0.07	0.62
Total emissions[f]	1.0	1.48	12.40	0.25	0.37	3.10	0.15	0.22	1.86

[a] All nonmethane. Mass of VOC emitted per mass of total solvent used are more accurate factors. Solvent assumed to consist entirely of VOC. Total solvent used includes all solvent in raw ink and related coatings, all dilution solvent added and all cleaning solvent used. Mass of VOC emitted per volume of raw ink (and coatings) used are general factors, based on typical dilution solvent volume addition. Actual factors based on ink use can vary significantly, as follows:

- Typical total solvent volume/raw ink (and coatings) volume ratio - 2.0 liter/liter (gal/gal); range, 1.6 - 2.4. See References 1, 5-8.
- Solvent density (D_s) varies with composition and temperature. At 21°C (70°F), the density of the most common mixed solvent used is 0.742 kg/liter (6.2 lb/gal); density of toluene solvent used is 0.863 kg/liter (7.2 lb/gal). See Reference 1.
- Mass of VOC emitted/raw ink (and coating) volume ratio determined from the mass emission factor ratio, the solvent/ink volume ratio, and the solvent density,

$$\text{kg/liter} = \text{kg/kg} \times \text{liter/liter} \times D_s$$
$$[\text{lb/gal} = \text{lb/lb} \times \text{gal/gal} \times D_s]$$

[b] Reference 3 and test data for presses with dryer exhaust control only (Reference 1). Dryer exhaust emissions depend on press operating speed, press shutdown frequency, ink and solvent composition, product printed, and dryer design and efficiencies. Emissions can range from 75-90% of total press emissions.

[c] Determined by difference between total emissions and other point emissions.

[d] Reference 1. Solvent temporarily retained in product after leaving press depends on dryer efficiency, type of paper and type of ink used. Emissions have been reported to range from 1-7% of total press emissions.

[e] Based on capture and control device efficiencies (see Note f). Emissions are residual content in captured solvent laden air vented after treatment.

[f] References 1 and 3. Uncontrolled presses eventually emit 100% of total solvent used. Controlled press emissions are based on overall reduction efficiency equal to capture efficiency x control device efficiency. For 75% control, the capture efficiency is 84% with a 90% efficient control device. For 85% control, the capture efficiency is 90% with a 95% control device.

other factors that affect the release of the solvent vapors from the print and web to the dryer air. Excessively high temperatures impair product quality. The capture efficiency of older design dryer exhaust systems is about 84 percent, and modern dryer systems can achieve 85 to 89 percent capture. For a typical press, this type capture system consists of ductwork from each printing unit's dryer exhaust joined in a large header. One or more large fans are employed to pull the solvent laden air from the dryers and to direct it to the control device.

A few facilities have increased capture efficiency by gathering fugitive solvent vapors along with the dryer exhausts. Fugitive vapors can be captured by a hood above the press, by a partial enclosure around the press, by a system of multiple spot pickup vents, by multiple floor sweep vents, by total pressroom ventilation capture, or by various combinations of these. The design of any fugitive vapor capture system needs to be versatile enough to allow safe and adequate access to the press in press shutdowns. The efficiencies of these combined dryer exhaust and fugitive capture systems can be as high as 93 to 97 percent at times, but the demonstrated achievable long term average when printing several types of products is only about 90 percent.

Control Devices - Various control devices and techniques may be employed to control captured VOC vapors from rotogravure presses. All such controls are of two categories, solvent recovery and solvent destruction.

Solvent recovery is the only present technique to control VOC emissions from publication presses. Fixed bed carbon adsorption by multiple vessels operating in parallel configuration, regenerated by steaming, represents the most used control device. A new adsorption technique using a fluidized bed of carbon might be employed in the future. The recovered solvent can be directly recycled to the presses.

There are three types of solvent destruction devices used to control VOC emissions, conventional thermal oxidation, catalytic oxidation and regenerative thermal combustion. These control devices are employed for other rotogravure printing. At present, none are being used on publication rotogravure presses.

The efficiency of both solvent destruction and solvent recovery control devices can be as high as 99 percent. However, the achievable long term average efficiency for publication printing is about 95 percent. Older carbon adsorber systems were designed to perform at about 90 percent efficiency. Control device emission factors presented in Table 4.9-1 represent the residual vapor content of the captured solvent laden air vented after treatment.

Overall Control - The overall emissions reduction efficiency for VOC control systems is equal to the capture efficiency times the control device efficiency. Emission factors for two control levels are presented in Table 4.9.2-1. The 75 percent control level represents 84 percent capture with a 90 percent efficient control device. (This is the EPA control techniques guideline recommendation for State regulations on old existing presses.) The 85 percent control level represents 90 percent capture with a 95 percent efficient control device. This corresponds to application of best demonstrated control technology for new publication presses.

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4.10 COMMERCIAL/CONSUMER SOLVENT USE

4.10.1 General[1,2]

Commercial and consumer use of various products containing volatile organic compounds (VOC) contributes to formation of tropospheric ozone. The organics in these products may be released through immediate evaporation of an aerosol spray, evaporation after application, and direct release in the gaseous phase. Organics may act either as a carrier for the active product ingredients or as active ingredients themselves. Commercial and consumer products which release volatile organic compounds include aerosols, household products, toiletries, rubbing compounds, windshield washing fluids, polishes and waxes, nonindustrial adhesives, space deodorants, moth control applications, and laundry detergents and treatments.

4.10.2 Emissions

Major volatile organic constituents of these products which are released to the atmosphere include special naphthas, alcohols and various chloro- and fluorocarbons. Although methane is not included in these products, 31 percent of the volatile organic compounds released in the use of these products is considered nonreactive under EPA policy.[3,4]

National emissions and per capita emission factors for commercial and consumer solvent use are presented in Table 4.10-1. Per capita emission factors can be applied to area source inventories by multiplying the factors by inventory area population. Note that adjustment to exclude the nonreactive emissions fraction cited above should be applied to total emissions or to the composite factor. Care is advised in making adjustments, in that substitution of compounds within the commercial/consumer products market may alter the nonreactive fraction of compounds.

References for Section 4.10

1. W.H. Lamason, "Technical Discussion of Per Capita Emission Factors for Several Area Sources of Volatile Organic Compounds", Monitoring and Data Analysis Division, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 15, 1981. Unpublished.

2. End Use of Solvents Containing Volatile Organic Compounds, EPA-450/3-79-032, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1979.

3. Final Emission Inventory Requirements for 1982 Ozone State Implementation Plans, EPA-450/4-80-016, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1980.

TABLE 4.10-1. EVAPORATIVE EMISSIONS FROM COMMERCIAL/CONSUMER SOLVENT USE

EMISSION FACTOR RATING: C

	Nonmethane VOC[a]					
	National Emissions		Per Capita Emission Factors			
Use	10^3 Mg/yr	10^3 tons/yr	kg/yr	lb/yr	g/day[b]	10^{-3} lb/day
Aerosol products	342	376	1.6	3.5	4.4	9.6
Household products	183	201	0.86	1.9	2.4	5.2
Toiletries	132	145	0.64	1.4	1.8	3.8
Rubbing compounds	62	68	0.29	0.64	0.80	1.8
Windshield washing	61	67	0.29	0.63	0.77	1.7
Polishes and waxes	48	53	0.22	0.49	0.59	1.3
Nonindustrial	29	32	0.13	0.29	0.36	0.79
Space deodorant	18	20	0.09	0.19	0.24	0.52
Moth control	16	18	0.07	0.15	0.19	0.41
Laundry detergent	4	4	0.02	0.04	0.05	0.10
Total[c]	895	984	4.2	9.2	11.6	25.2

[a] References 1 and 2.

[b] Calculated by dividing kg/yr (lb/yr) by 365 and converting to appropriate units.

[c] Totals may not be additive because of rounding.

4. *Procedures for the Preparation of Emission Inventories for Volatile Organic Compounds, Volume I, Second Edition*, EPA-450/2-77-028, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1980.

5.17 SULFURIC ACID

5.17.1 General

All sulfuric acid is made by either the lead chamber process or the contact process. Because the contact process accounts for more than 97 percent of the total sulfuric acid production in the United States, it is the only process discussed in this Section. Contact plants are generally classified according to the raw materials charged to them - (1) elemental sulfur burning, (2) spent acid and hydrogen sulfide burning, and (3) sulfide ores and smelter gas burning. The contributions from these plants to the total acid production are 68, 18.5 and 13.5 percent respectively.

All contact processes incorporate three basic operations, each of which corresponds to a distinct chemical reaction. First, the sulfur in the feedstock is burned to sulfur dioxide:

$$\underset{\text{Sulfur}}{S} + \underset{\text{Oxygen}}{O_2} \rightarrow \underset{\substack{\text{Sulfur}\\ \text{dioxide}}}{SO_2} \tag{1}$$

Then, the sulfur dioxide is catalytically oxidized to sulfur trioxide:

$$\underset{\substack{\text{Sulfur}\\ \text{dioxide}}}{2SO_2} + \underset{\text{Oxygen}}{O_2} \rightarrow \underset{\substack{\text{Sulfur}\\ \text{trioxide}}}{2SO_3} \tag{2}$$

Finally, the sulfur trioxide is absorbed in a strong aqueous solution of sulfuric acid:

$$\underset{\substack{\text{Sulfur}\\ \text{trioxide}}}{SO_3} + \underset{\text{Water}}{H_2O} \rightarrow \underset{\substack{\text{Sulfuric}\\ \text{acid}}}{H_2SO_4} \tag{3}$$

Elemental Sulfur Burning Plants[1,2] - Elemental sulfur, such as Frasch process sulfur from oil refineries, is melted, settled or filtered to remove ash and is fed into a combustion chamber. The sulfur is burned in clean air that has been dried by scrubbing with 93 - 99 percent sulfuric acid. The gases from the combustion chamber cool and then enter the solid catalyst (vanadium pentoxide) converter. Usually, 95 - 98 percent of the sulfur dioxide from the combustion chamber is converted to sulfur trioxide, with an accompanying large evolution of heat. After being cooled, the converter exit gas enters an absorption tower, where the sulfur trioxide is absorbed with 98 - 99 percent sulfuric acid. The sulfur trioxide combines with the water in the acid and forms more sulfuric acid.

If oleum, a solution of uncombined SO_3 in H_2SO_4, is produced, SO_3 from the converter is first passed to an oleum tower that is fed with 98 percent acid from the absorption system. The gases

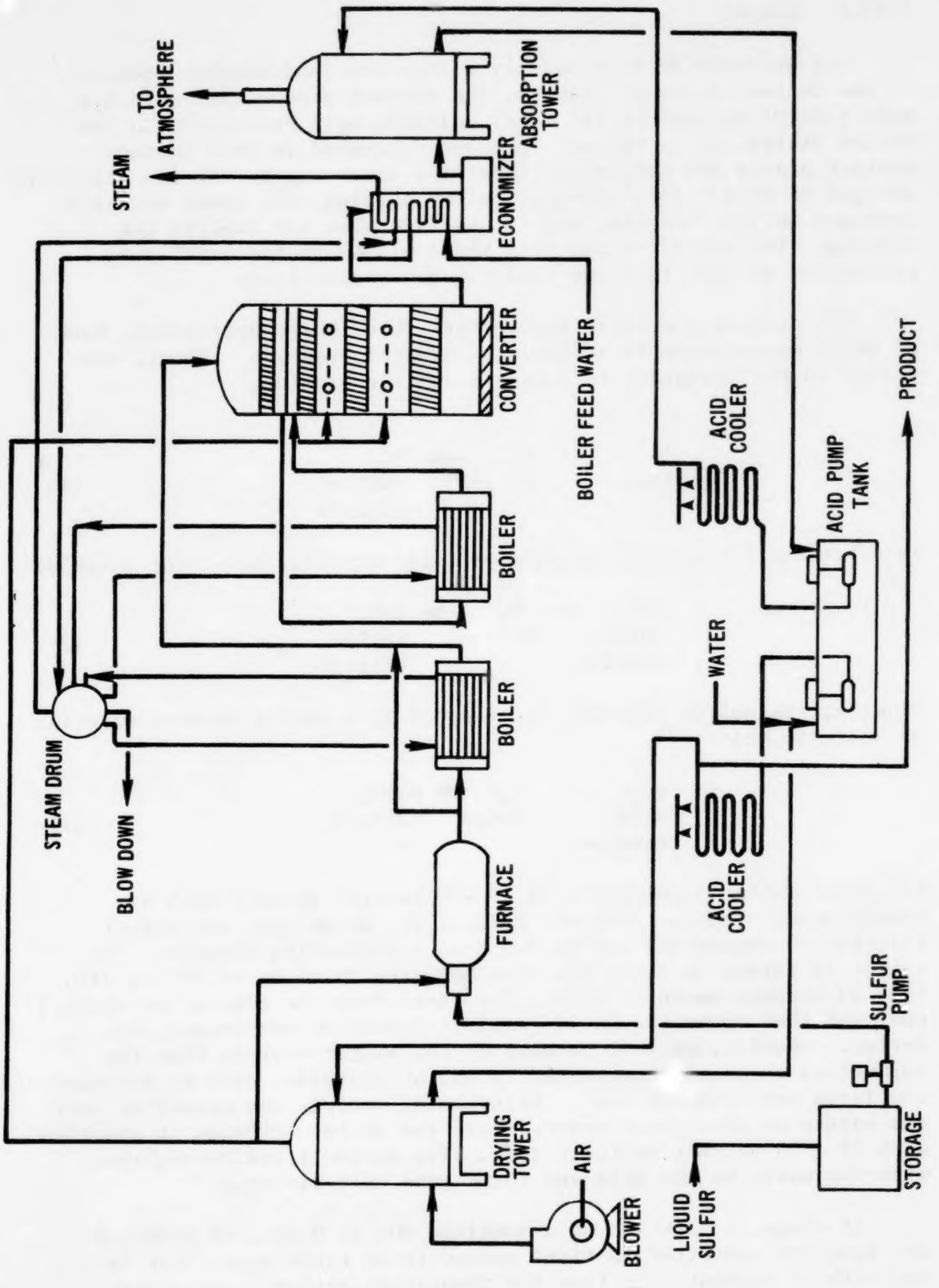
TO ATMOSPHERE
STEAM
ABSORPTION TOWER
ECONOMIZER
CONVERTER
BOILER FEED WATER
ACID COOLER
PRODUCT
ACID PUMP TANK
BOILER
BOILER
WATER
STEAM DRUM
BLOW DOWN
FURNACE
ACID COOLER
SULFUR PUMP
DRYING TOWER
AIR
BLOWER
LIQUID SULFUR
STORAGE

Figure 5.17-1. Basic flow diagram of contact process sulfuric acid plant burning elemental sulfur.

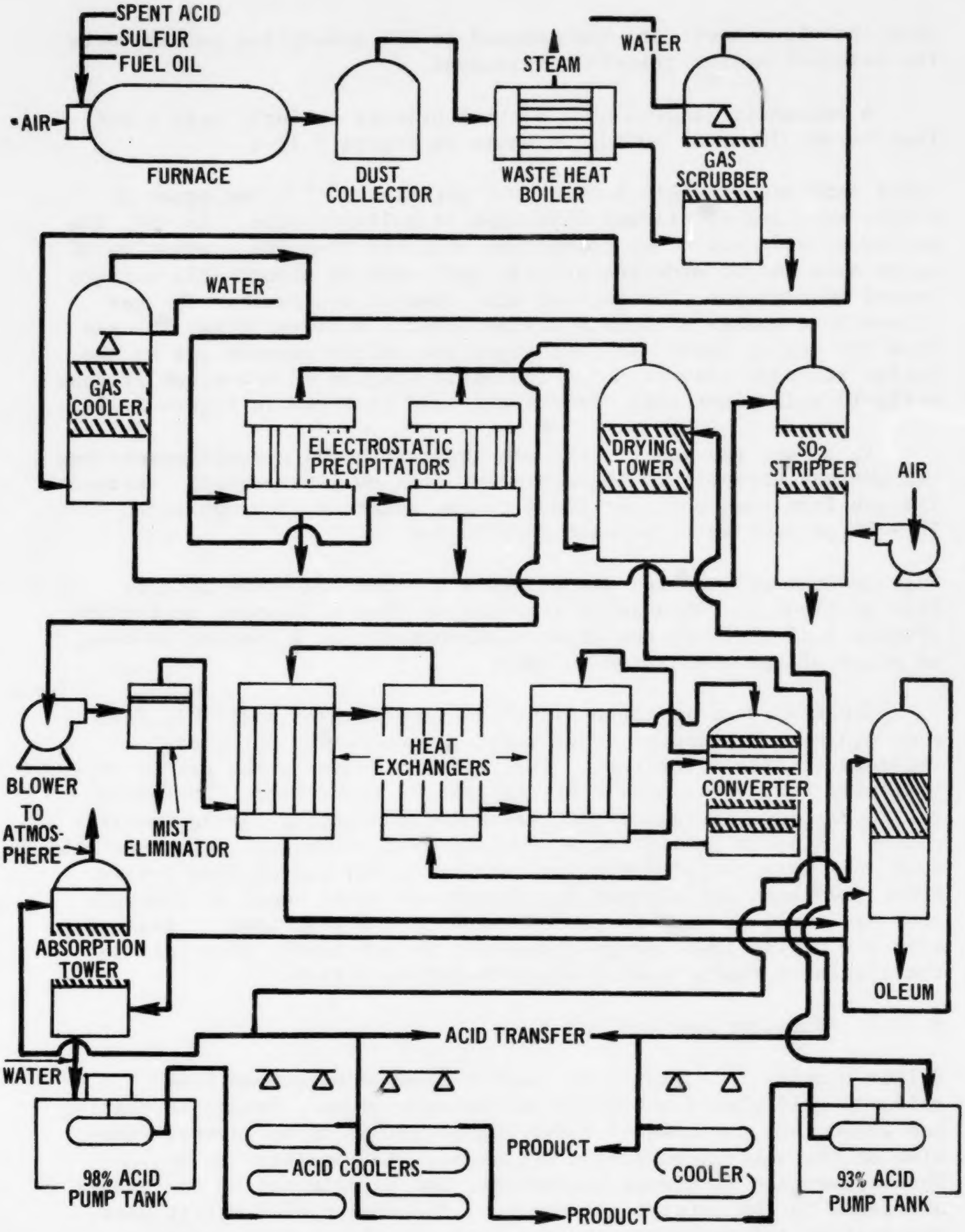
SPENT ACID
SULFUR
FUEL OIL
AIR
FURNACE
DUST COLLECTOR
STEAM
WASTE HEAT BOILER
WATER
GAS SCRUBBER
WATER
GAS COOLER
ELECTROSTATIC PRECIPITATORS
DRYING TOWER
SO2 STRIPPER
AIR
BLOWER
MIST ELIMINATOR
HEAT EXCHANGERS
CONVERTER
TO ATMOSPHERE
ABSORPTION TOWER
OLEUM
WATER
ACID TRANSFER
98% ACID PUMP TANK
ACID COOLERS
PRODUCT
PRODUCT
COOLER
93% ACID PUMP TANK

Figure 5.17-2. Basic flow diagram of contact process sulfuric acid plant burning spent acid.

from the oleum tower are then pumped to the absorption column where the residual sulfur trioxide is removed.

A schematic diagram of a contact process sulfuric acid plant that burns elemental sulfur is shown in Figure 5.17-1.

Spent Acid and Hydrogen Sulfide Burning Plants[1,2] - Two types of plants are used to process this type of sulfuric acid. In one, the sulfur dioxide and other combustion products from the combustion of spent acid and/or hydrogen sulfide with undried atmospheric air are passed through gas cleaning and mist removal equipment. The gas stream next passes through a drying tower. A blower draws the gas from the drying tower and discharges the sulfur dioxide gas to the sulfur trioxide converter. A schematic diagram of a contact process sulfuric acid plant that burns spent acid is shown in Figure 5.17-2.

In a "wet gas plant", the wet gases from the combustion chamber are charged directly to the converter with no intermediate treatment. The gas from the converter flows to the absorber, through which 93 - 98 percent sulfuric acid is circulating.

Sulfide Ores and Smelter Gas Plants - The configuration of this type of plant is essentially the same as that of a spent acid plant (Figure 5.17-2), with the primary exception that a roaster is used in place of the combustion furnace.

The feed used in these plants is smelter gas, available from such equipment as copper converters, reverberatory furnaces, roasters and flash smelters. The sulfur dioxide in the gas is contaminated with dust, acid mist and gaseous impurities. To remove the impurities, the gases must be cooled and passed through purification equipment consisting of cyclone dust collectors, electrostatic dust and mist precipitators, and scrubbing and gas cooling towers. After the gases are cleaned and the excess water vapor is removed, they are scrubbed with 98 percent acid in a drying tower. Beginning with the drying tower stage, these plants are nearly identical to the elemental sulfur plants shown in Figure 5.17-1.

5.17.2 Emissions and Controls

Sulfur Dioxide[1-3] - Nearly all sulfur dioxide emissions from sulfuric acid plants are found in the exit gases. Extensive testing has shown that the mass of these SO_2 emissions is an inverse function of the sulfur conversion efficiency (SO_2 oxidized to SO_3). This conversion is always incomplete, and is affected by the number of stages in the catalytic converter, the amount of catalyst used, temperature and pressure, and the concentrations of the reactants (sulfur dioxide and oxygen). For example, if the inlet SO_2 concentration to the converter were 8 percent by volume (a representative value), and the conversion temperature were 473°C (883°F), the conversion efficiency would be 96 percent. At this conversion, the uncontrolled emission factor for SO_2 would be 27.5 kg/Mg (55 pounds per ton) of 100 percent sulfuric acid produced, as shown in Table 5.17-1. For purposes of comparison, note that the Environmental Protection Agency performance standard for new and modified plants is 2 kg/Mg (4 pounds per ton) of 100 percent acid produced, maximum 2 hour average.[3] As Table 5.17-1 and Figure 5.17-3 indicate, achieving this standard requires a conversion efficiency of 99.7 percent in an uncontrolled plant or the equivalent SO_2 collection mechanism in a controlled facility. Most single absorption plants have SO_2 conversion efficiencies ranging from 95 - 98 percent.

In addition to exit gases, small quantities of sulfur oxides are emitted from storage tank vents and tank car and tank truck vents during loading operations, from sulfuric acid concentrators, and through leaks in process equipment. Few data are available on the quantity of emissions from these sources.

Of the many chemical and physical means for removing SO_2 from gas streams, only the dual absorption and the sodium sulfite/bisulfite scrubbing processes have been found to increase acid production without yielding unwanted byproducts.

TABLE 5.17-1. EMISSION FACTORS FOR SULFURIC ACID PLANTS[a]

EMISSION FACTOR RATING: A

	SO_2 Emissions	
Conversion of SO_2 to SO_3 (%)	kg/Mg of 100% H_2SO_4	lb/ton of 100% H_2SO_4
93	48.0	96
94	41.0	82
95	35.0	70
96	27.5	55
97	20.0	40
98	13.0	26
99	7.0	14
99.5	3.5	7
99.7	2.0	4
100	0.0	0

[a] Reference 1.

[b] This linear interpolation formula can be used for calculating emission factors for conversion efficiencies between 93 and 100%: emission factor = 13.65 (% conversion efficiency) + 1365.

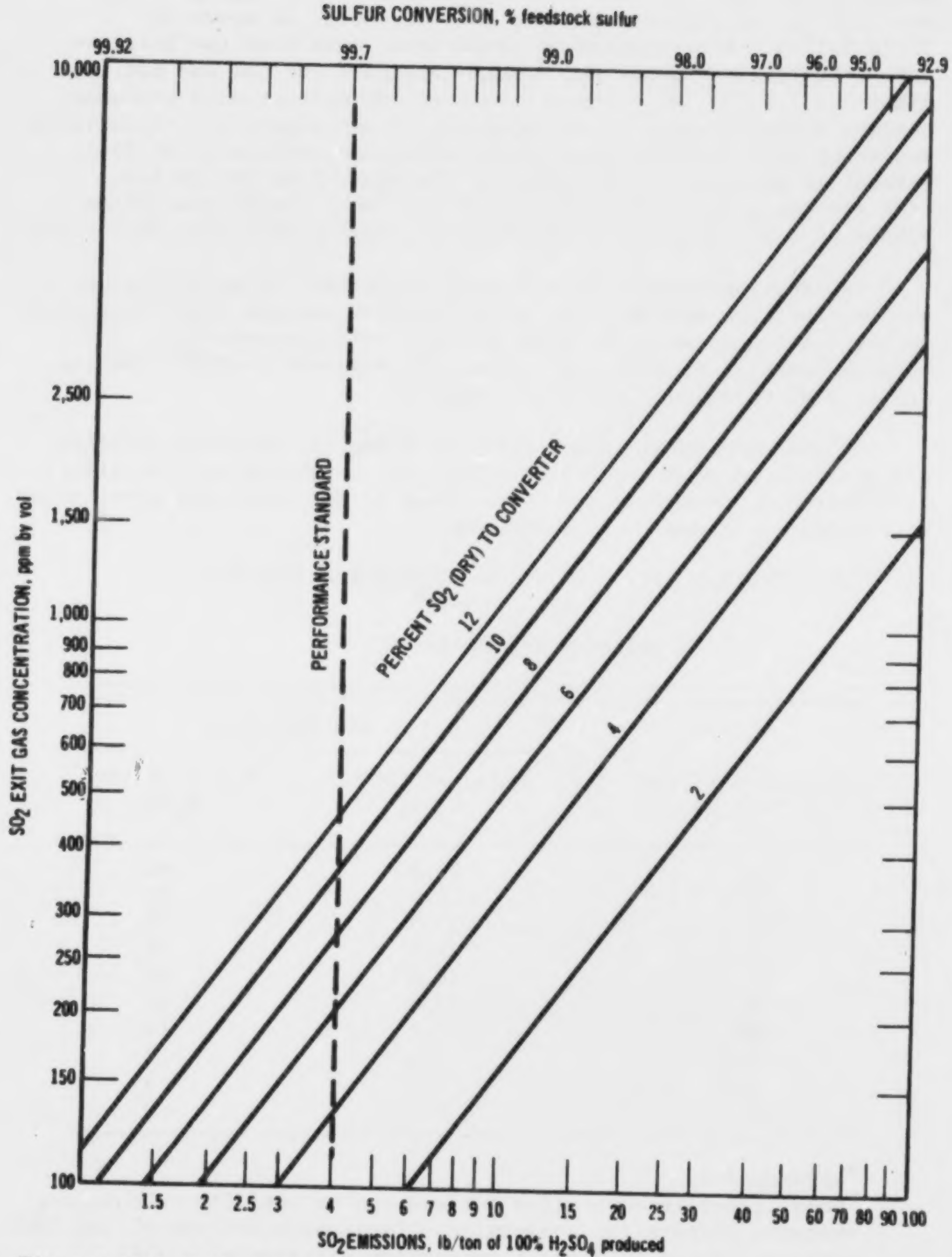

Figure 5.17-3. Sulfuric acid plant feedstock sulfur conversion versus volumetric and mass SO_2 emissions at various inlet SO_2 concentrations by volume.

In the dual absorption process, the SO_3 gas formed in the primary converter stages is sent to a primary absorption tower where most of the SO_3 is removed to form H_2SO_4. The remaining unconverted sulfur dioxide is forwarded to the final stages in the converter to remove much of the remaining SO_2 by oxidation to SO_3, from whence it is sent to the secondary absorber for final sulfur trioxide removal. The result is the conversion of a much higher fraction of SO_2 to SO_3 (a conversion of 99.7 percent or higher, on the average, which meets the performance standard). Furthermore, dual absorption permits higher converter inlet sulfur dioxide concentrations than are used in single absorption plants, because the secondary conversion stages effectively remove any residual sulfur dioxide from the primary absorber.

Where dual absorption reduces sulfur dioxide emissions by increasing the overall conversion efficiency, the sodium sulfite/bisulfite scrubbing process removes sulfur dioxide directly from the absorber exit gases. In one version of this process, the sulfer dioxide in the waste gas is absorbed in a sodium sulfite solution, is separated, and is recycled to the plant. Test results from a 680 Mg (750 ton per day) plant equipped with a sulfite scrubbing system indicated an average SO_2 emission factor of 1.35 kg/Mg (2.7 pounds per ton) of 100 percent acid.

Acid Mist[1-3] - Nearly all the acid mist emitted from sulfuric acid manufacturing can be traced to the absorber exit gases. Acid mist is created when sulfur trioxide combines with water vapor at a temperature below the dew point of sulfur trioxide. Once formed within the process system, this mist is so stable that only a small quantity can be removed in the absorber.

In general, the quantity and particle size distribution of acid mist are dependent on the type of sulfur feedstock used, the strength of acid produced, and the conditions in the absorber. Because it contains virtually no water vapor, bright elemental sulfur produces little acid mist when burned. However, the hydrocarbon impurities in other feedstocks - dark sulfur, spent acid and hydrogen sulfide - oxidize to water vapor during combustion. The water vapor, in turn, combines with sulfur trioxide as the gas cools in the system.

The strength of acid produced - whether oleum or 99 percent sulfuric acid - also affects mist emissions. Oleum plants produce greater quantities of finer more stable mist. For example, uncontrolled mist emissions from oleum plants burning spent acid range from 0.5 to 5.0 kg/Mg (1.0 to 10.0 pounds per ton), while those from 98 percent acid plants burning elemental sulfur range from 0.2 to 2.0 kg/Mg (0.4 to 4.0 pounds per ton). Furthermore, 85 - 95 weight percent of the mist particles from oleum plants are less than 2 microns in diameter, compared with only 30 weight percent that are less than 2 microns in diameter from 98 percent acid plants.

The operating temperature of the absorption column directly affects sulfur trioxide absorption and, accordingly, the quality of acid mist formed after exit gases leave the stack. The optimum absorber operating temperature depends on the strength of the acid produced, throughput rates, inlet sulfur trioxide concentrations, and other variables peculiar to each individual plant. Finally, it should be emphasized that the percentage conversion of sulfur trioxide has no direct effect on acid mist emissions. In Table 5.17-2, uncontrolled acid mist emissions are presented for various sulfuric acid plants.

TABLE 5.17-2. ACID MIST EMISSION FACTORS FOR SULFURIC ACID PLANTS WITHOUT CONTROLS[a]

EMISSIONS FACTOR RATING: B

Raw material	Oleum produced, % total output	Emissions[b] kg/Mg acid	Emissions[b] lb/ton acid
Recovered sulfur	0 to 43	0.175 - 0.4	0.35 - 0.8
Bright virgin sulfur	0	0.85	1.7
Dark virgin sulfur	33 to 100	0.16 - 3.15	0.32 - 6.3
Sulfide ores	0 to 25	0.6 - 3.7	1.2 - 7.4
Spent acid	0 to 77	1.1 - 1.2	2.2 - 2.4

[a] Reference 1.

[b] Emissions are proportional to the percentage of oleum in the total product. Use low end of ranges for low oleum percentage and high end of ranges for high oleum percentage.

Two basic types of devices, electrostatic precipitators and fiber mist eliminators, effectively reduce the acid mist concentration from contact plants to less than the EPA New Source Performance Standard, which is 0.075 kg/Mg (0.15 pound per ton) of acid. Precipitators, if properly maintained, are effective in collecting the mist particles at efficiencies up to 99 percent (see Table 5.17-3).

The three most commonly used fiber mist eliminators are the vertical tube, vertical panel, and horizontal dual pad types. They differ from one another in the arrangement of the fiber elements, which are composed of either chemically resistant glass or fluorocarbon, and in the means employed to collect the trapped liquid. The operating characteristics of these three types are compared with electrostatic precipitators in Table 5.17-3.

TABLE 5.17-3. EMISSION COMPARISON AND COLLECTION EFFICIENCY OF TYPICAL ELECTROSTATIC PRECIPITATOR AND FIBER MIST ELIMINATORS[a]

Control device	Particle size collection efficiency, %		Acid mist emissions			
			98% acid plants[b]		Oleum plants	
	>3 μm	≤3μm	kg/Mg	lb/ton	kg/Mg	lb/ton
Electrostatic precipitator	99	100	0.05	0.10	0.06	0.12
Fiber mist eliminator						
Tabular	100	95-99	0.01	0.02	0.01	0.02
Panel	100	90-98	0.05	0.10	0.05	0.10
Dual pad	100	93-99	0.055	0.11	0.055	0.11

[a] Reference 2.

[b] Based on manufacturers' generally expected results. Calculated for 8% SO_2 concentration in gas converter.

References for Section 5.17

1. Atmospheric Emissions from Sulfuric Acid Manufacturing Processes, 999-AP-13, U.S. Department of Health, Education and Welfare, Washington, DC, 1966.

2. Unpublished report on control of air pollution from sulfuric acid plants, U.S. Environmental Protection Agency, Research Triangle Park, NC, August 1971.

3. Standards of Performance for New Stationary Sources, 36 FR 24875, December 23, 1971.

4. M. Drabkin and Kathryn J. Brooks, A Review of Standards of Performance for New Stationary Sources - Sulfuric Acid Plants, EPA Contract No. 68-02-2526, Mitre Corporation, McLean, VA, June 1978.

5. Final Guideline Document: Control of Sulfuric Acid Mist Emissions from Existing Sulfuric Acid Production Units, EPA 450/2-77-019, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1977.

6.5 FERMENTATION

Process Description[1]

For the purpose of this report only the fermentation industries associated with food will be considered. This includes the production of beer, whiskey, and wine.

The manufacturing process for each of these is similar. The four main brewing production stages and their respective sub-stages are: (1) brewhouse operations, which include (a) malting of the barley, (b) addition of adjuncts (corn, grits, and rice) to barley mash, (c) conversion of starch in barley and adjuncts to maltose sugar by enzymatic processes, (d) separation of wort from grain by straining, and (e) hopping and boiling of the wort; (2) fermentation, which includes (a) cooling of the wort, (b) additional yeast cultures, (c) fermentation for 7 to 10 days, (d) removal of settled yeast, and (e) filtration and carbonation; (3) aging, which lasts from 1 to 2 months under refrigeration; and (4) packaging, which includes (a) bottling-pasteurization, and (b) racking draft beer.

The major differences between beer production and whiskey production are the purification and distillation necessary to obtain distilled liquors and the longer period of aging. The primary difference between wine making and beer making is that grapes are used as the initial raw material in wine rather than grains.

Table 6.5-1. EMISSION FACTORS FOR FERMENTATION PROCESSES
EMISSION FACTOR RATING: E

Type of product	Particulates		Hydrocarbons	
	lb/ton	kg/MT	lb/ton	kg/MT
Beer				
Grain handling[a]	See Subsection 6.5.1			
Drying spent grains, etc.[a]				
Whiskey				
Grain handling[a]	3	1.5	–	–
Drying spent grains, etc.[a]	5	2.5	NA	NA
Aging	–	–	10[c]	0.024[d]
Wine	See Subsection 6.5.2			

[a] Based on section on grain processing

[b] No emission factor available, but emissions do occur.

[c] Pounds per year per barrel of whiskey stored.[2]

[d] Kilograms per year per liter of whiskey stored.

[e] No significant emissions.

References for Section 6.5

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Shreve, R.N. Chemical Process Industries, 3rd Ed. New York, McGraw-Hill Book Company. 1967. p. 591-608.

6.5.1. BEER MAKING

6.5.1.1 General[1-3]

Beer is a beverage of low alcoholic content (2 - 7 percent) made by the fermentation of malted starchy cereal grains. Barley is the principal grain used. The production of beer is carried out in four major stages, brewhouse operations, fermentation, aging and packaging. These processes are shown in Figure 6.5.1-1.

Brewhouse operations include malting of the barley, addition of adjuncts to the barley mash, conversion of the starch in the barley and adjuncts to maltose sugar, separation of wort from the grain, and hopping and boiling of the wort.

In malting, barley is continuously moistened to cause it to germinate. With germination, enzymes are formed which break down starches and proteins to less complex water soluble compounds. The malted barley is dried to arrest the enzyme formation and is ground in a malt or roll mill. Adjuncts, consisting of other grains (ground and unmalted), sugars and syrups, are added to the ground malted barley and, with a suitable amount of water, are charged to the mash tun (tank-like vessel). Conversion of the complex carbohydrates (starch and sugars) and proteins to simpler water soluble fermentable compounds by means of enzyme action takes place in the mash tun, a process called mashing. The mash is sent to a filter press or straining tub (lauter tun) where the wort (unfermented beer) is separated from the spent grain solids. Hops are added to the wort in a brew kettle, where the wort is boiled one and a half to three hours to extract essential substances from the hops, to concentrate the wort, and to destroy the malt enzymes. The wort is strained to remove hops, and sludge is removed by a filter or centrifuge.

Wort is cooled to 10°C (50°F) or lower. During cooling, it absorbs air necessary to start fermentation. The yeast is added and mixed with the wort in line to the fermentation starter tanks. Fermentation, the conversion of the simple sugars in the wort to ethanol and carbon dioxide, is completed in a closed fermenter. The carbon dioxide gas released by the fermentation is collected and later used for carbonating the beer. Cooling to maintain proper fermentation temperature is required because the reaction is exothermic.

After fermentation is complete, beer is stored to age for several weeks at 0°C (32°F) in large closed tanks. It is recarbonated, pumped through a pulp filter, pasteurized at 60°C (140°F) to make it biologically stable, and packaged in bottles and cans. Beer put in kegs for draft sale is not pasteurized.

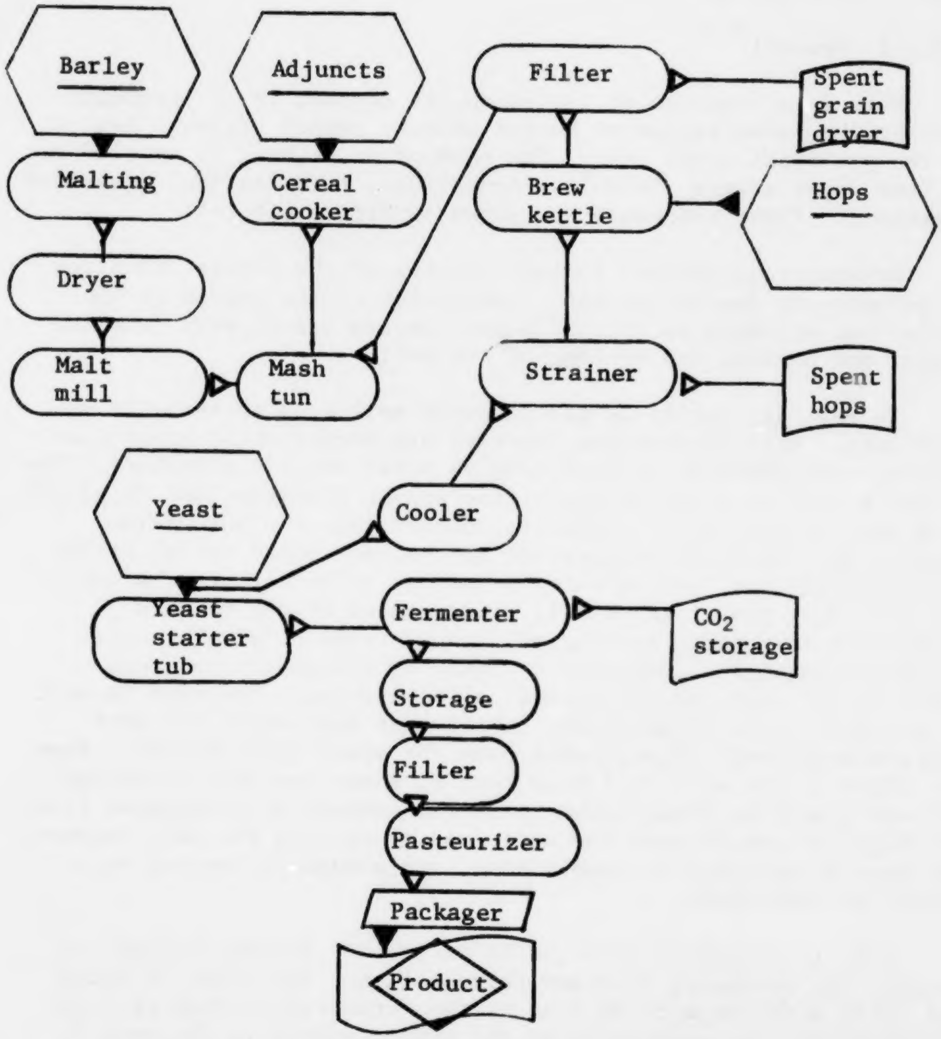
Barley
Adjuncts
Filter
Spent grain dryer
Malting
Cereal cooker
Brew kettle
Hops
Dryer
Malt mill
Mash tun
Strainer
Spent hops
Yeast
Cooler
Yeast starter tub
Fermenter
CO_2 storage
Storage
Filter
Pasteurizer
Packager
Product

Figure 6.5.1-1. Flow diagram of a beer making process.

6.5.1.2 Emissions and Controls[2-7]

The major emissions from beer making and their sources are particulates and volatile organics, mainly ethanol, from spent grain drying, and particulates from grain handling. Volatile organics (VOC) from fermentation are negligible, and they are fugitive because the fermenters are closed to provide for collecting carbon dioxide. Other brewery processes are minor sources of volatile organics, ethanol and related compounds, such as boiling wort in the brew kettle and malt drying. An estimate of these emissions is not available.

Fugitive particulate emissions from grain handling and milling at breweries are reduced by operating in well ventilated, low pressure conditions. At grain handling and milling operations, fabric filters are most often used for dust collection. Organics and organic particulate matter from spent grain drying can be controlled by mixing the dryer exhaust with the combustion air of a boiler. A centrifugal fan wet scrubber is the most commonly used control.

TABLE 6.5.1-1. EMISSION FACTORS FOR BEER BREWING[a]

EMISSION FACTOR RATING: D

Source	Particulate	Volatile Organic Compounds
Grain handling	1.5 (3)[b]	
Brew kettle		NA[c]
Spent grain drying	2.5 (5)[b]	1.31 (2.63)[d]
Cooling units		NA[c]
Fermentation		Neg[e]

[a] Expressed in terms of kg/10^6g (lb/ton) of grain handled. Blanks indicate no emissions.

[b] Reference 6.

[c] Factors not available, but negligible amounts of ethanol emissions are suspected.

[d] Reference 4. Mostly ethanol.

[e] Negligible amounts of ethanol, ethyl acetate, isopropyl alcohol, n-propyl alcohol, isoamyl alcohol, and isoamyl acetate emissions are suspected.

References for Section 6.5.1

1. H.E. Høyrup, "Beer and Brewing", Kirk-Othmer Encyclopedia of Chemical Technology, Volume 3, John Wiley and Sons, Inc., New York, 1964, pp. 297-338.

2. R. Norris Shreve, Chemical Process Industries, 3rd Ed., McGraw-Hill Book Company, New York, 1967, pp. 603-605.

3. E.C. Cavanaugh, et al., Hydrocarbon Pollutants from Stationary Sources, EPA-600/7-77-110, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1977.

4. H.W. Bucon, et al., Volatile Organic Compound (VOC) Species Data Manual, Second Edition, EPA-450/4-80-015, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1978.

5. Melvin W. First, et al., "Control of Odors and Aerosols from Spent Grain Dryers", Journal of the Air Pollution Control Association, 24(7): 653-659, July 1974.

6. AEROS Manual Series, Volume V: AEROS Manual of Codes, EPA-450/2-76-005, U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1976.

7. Peter N. Formica, Controlled and Uncontrolled Emission Rates and Applicable Limitations for Eighty Processes, EPA-340/1-78-004, U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1978.

6.18 AMMONIUM SULFATE MANUFACTURE

6.18.1 General[1]

Ammonium sulfate, $[NH_4]_2SO_4$, is commonly used as a fertilizer. About 90 percent of ammonium sulfate is produced by three types of facilities, caprolactam byproduct, synthetic, and coke oven byproduct plants. The remainder is produced as a byproduct of nickel manufacture from ore concentrates, methyl methacrylate manufacture, and ammonia scrubbing of tail gas at sulfuric acid plants.

During the manufacture of caprolactam, $[CH_2]_5COHN$, ammonium sulfate is produced from the oximation process stream and the rearrangement reaction stream. Synthetic ammonium sulfate is produced by the direct combination of ammonia and sulfuric acid in a reactor. Coke oven byproduct ammonium sulfate is produced by reacting ammonia recovered from coke oven offgas with sulfuric acid. Figure 6.18-1 is a process flow diagram for each of the three primary commercial processes.

After formation of the ammonium sulfate solution, operations of each process are similar. Ammonium sulfate crystals are formed by continuously circulating an ammonium sulfate liquor through an evaporator to thicken the solution. Ammonium sulfate crystals are separated from the liquor in the centrifuge. The saturated liquor is returned to the dilute ammonium sulfate brine of the evaporator. The crystals, with about 1 to 2.5 percent moisture by weight after the centrifuge, are fed to either a fluidized bed or rotary drum dryer. Fluidized bed dryers are continuously steam heated, and rotary dryers are either directly fired with oil or natural gas, or they use steam heated air. At coke oven byproduct plants, rotary drum dryers may be used in place of a centrifuge and dryer. On the filter of these dryers, a crystal layer is deposited which is removed from the drum by a scraper or a knife.

The volume of ammonium sulfate in the dryer exhaust gas varies according to production process and dryer type. A gas flow rate of 620 scm/Mg of product (20,000 scf/ton) is considered representative of a direct fired rotary drum dryer. A gas flow of 2,500 scm/Mg of product (80,000 scf/ton) is considered representative of a steam heated fluidized bed dryer. Dryer exhaust gases are passed through a particulate collection device, usually a wet scrubber, for product recovery and for pollution control.

The ammonium sulfate crystals are conveyed from the dryer to an enclosure where they are screened to product specifications, generally to coarse and fine products. The screening is enclosed to control dust in the building.

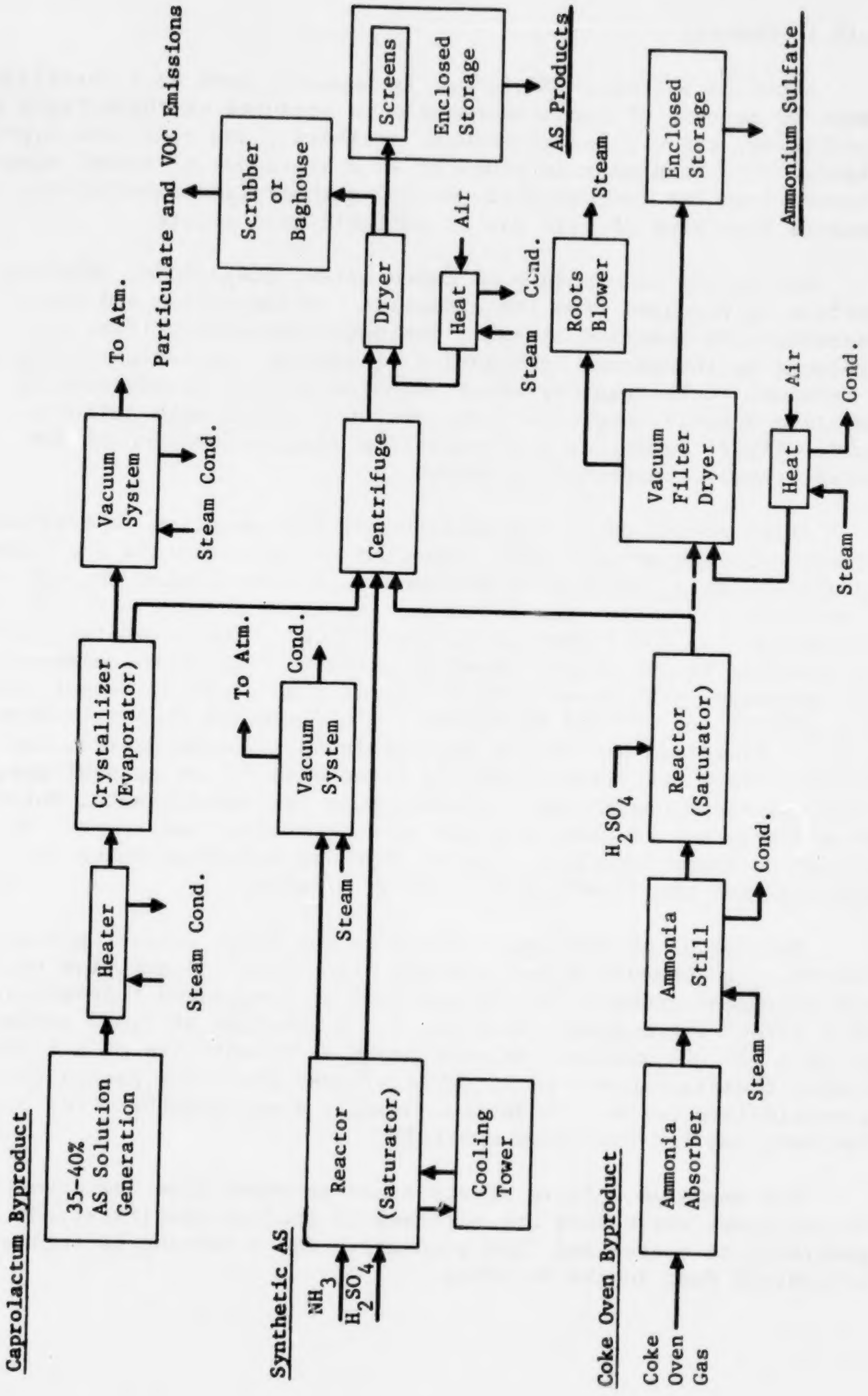
Caprolactum Byproduct
35-40% AS Solution Generation
Heater
Steam
Cond.
Crystallizer (Evaporator)
Vacuum System
Steam
Cond.
To Atm.
Particulate and VOC Emissions
Synthetic AS
NH3
H2SO4
Reactor (Saturator)
Cooling Tower
Vacuum System
Steam
To Atm.
Cond.
Centrifuge
Dryer
Heat
Air
Steam
Cond.
Scrubber or Baghouse
Screens
Enclosed Storage
AS Products
Coke Oven Byproduct
Coke Oven Gas
Ammonia Absorber
Ammonia Still
Steam
Cond.
H2SO4
Reactor (Saturator)
Vacuum Filter Dryer
Heat
Air
Steam
Cond.
Roots Blower
Steam
Enclosed Storage
Ammonium Sulfate

Figure 6.18-1. Diagram of Ammonium Sulfate (AS) processes.

6.18.2 Emissions and Controls

Ammonium sulfate particulate is the principal pollutant emitted to the atmosphere from the manufacturing plants, nearly all of it being contained in the gaseous exhaust of the dryers. Other plant processes, such as evaporation, screening, and materials handling, are not significant sources of emissions.

The particulate emission rate of a dryer depends on the gas velocity and the particle size distribution. Since gas velocity varies according to the dryer type, emission rates also vary. Generally, the gas velocity of fluidized bed dryers is higher than for most rotary drum dryers, and particulate emission rates are also higher. The smaller the particle, the easier it is removed by the gas stream of either type of dryer.

At caprolactam byproduct plants, volatile organic compounds (VOC) are emitted from the dryers. Emissions of caprolactam vapor are at least two orders of magnitude lower than the particulate emissions.

Wet scrubbers, such as venturi and centrifuge, are most suitable for reducing particulate emissions from the dryers. Wet scrubbers use process streams as the scrubbing liquid. This allows the collected particulate to be recycled easily to the production system.

Table 6.18-1 shows the uncontrolled and controlled emission factors for the various dryer types. The VOC emissions shown in Table 6.18-1 apply only to caprolactam byproduct plants which may use either a fluidized bed or rotary drum dryer.

TABLE 6.18-1. EMISSION FACTORS FOR AMMONIUM SULFATE MANUFACTURE[a]

EMISSION FACTOR RATING: B

Dryer Type & Controls	Particulates		Volatile Organic Compounds[b]	
	kg/Mg	lb/ton	kg/Mg	lb/ton
Rotary dryers				
Uncontrolled	23	46	0.74	1.48
Wet scrubber	0.12	0.24	0.11	0.22
Fluidized bed dryers				
Uncontrolled	109	218	0.74	1.48
Wet scrubber	0.14	0.28	0.11	0.22

[a] Expressed as emissions by weight per unit of ammonium sulfate production by weight.

[b] VOC emissions occur only at caprolactam plants using either type of dryer. The emissions are caprolactam vapor.

Reference for Section 6.18

1. Ammonium Sulfate Manufacture - Background Information for Proposed Emission Standards, EPA-450/3-79-034a, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1979.

7.1 PRIMARY ALUMINUM PRODUCTION

7.1.1 Process Description[1,2]

The base ore for primary aluminum production is bauxite, a hydrated oxide of aluminum consisting of 30 to 70 percent alumina (Al_2O_3) and lesser amounts of iron, silicon and titanium. The bauxite ore is first purified to alumina by the Bayer process, and this is then reduced to elemental aluminum. The production of alumina and the reduction of alumina to aluminum are seldom accomplished at the same location. A schematic diagram of the primary production of aluminum is shown at Figure 7.1-1.

In the Bayer process, the ore is dried, ground in ball mills and mixed with sodium hydroxide to yield aluminum hydroxide. Iron oxide, silica and other impurities are removed by settling, dilution and filtration. Aluminum hydroxide is precipitated from the solution by cooling and is then calcined to produce pure alumina, as in the reaction:

$$\underset{\text{Aluminum hydroxide}}{2\ Al(OH)_3} \xrightarrow{\text{heat}} \underset{\text{Water}}{3\ H_2O} + \underset{\text{Alumina}}{Al_2O_3} \qquad (1)$$

Aluminum metal is manufactured by the Hall-Heroult process, which involves the electrolytic reduction of alumina dissolved in a molten salt bath of cryolite (Na_3AlF_6) and various salt additives:

$$\underset{\text{Alumina}}{2Al_2O_3} \xrightarrow{\text{Electrolysis}} \underset{\text{Aluminum}}{4Al} + \underset{\text{Oxygen}}{3O_2} \qquad (2)$$

The electrolysis occurs in shallow rectangular cells, or "pots", which are steel shells lined with carbon. Carbon blocks extending into the pot serve as the anodes, and the carbon lining the steel shell acts as the cathode. Cryolite functions as both the electrolyte and the solvent for the alumina. Electrical resistance to the current passing between the electrodes generates heat that maintains cell operating temperatures between 950° and 1000°C (1730° and 1830°F). Aluminum is deposited at the cathode, where it remains as molten metal below the surface of the cryolite bath. The carbon anodes are continuously depleted by the reaction of oxygen (formed during the reaction) and anode carbon, to produce carbon monoxide and carbon dioxide. The carbon consumption and other raw material and energy requirements for aluminum production are summarized in Table 7.1-1. The aluminum product is periodically tapped beneath the cryolite cover and is fluxed to remove trace impurities.

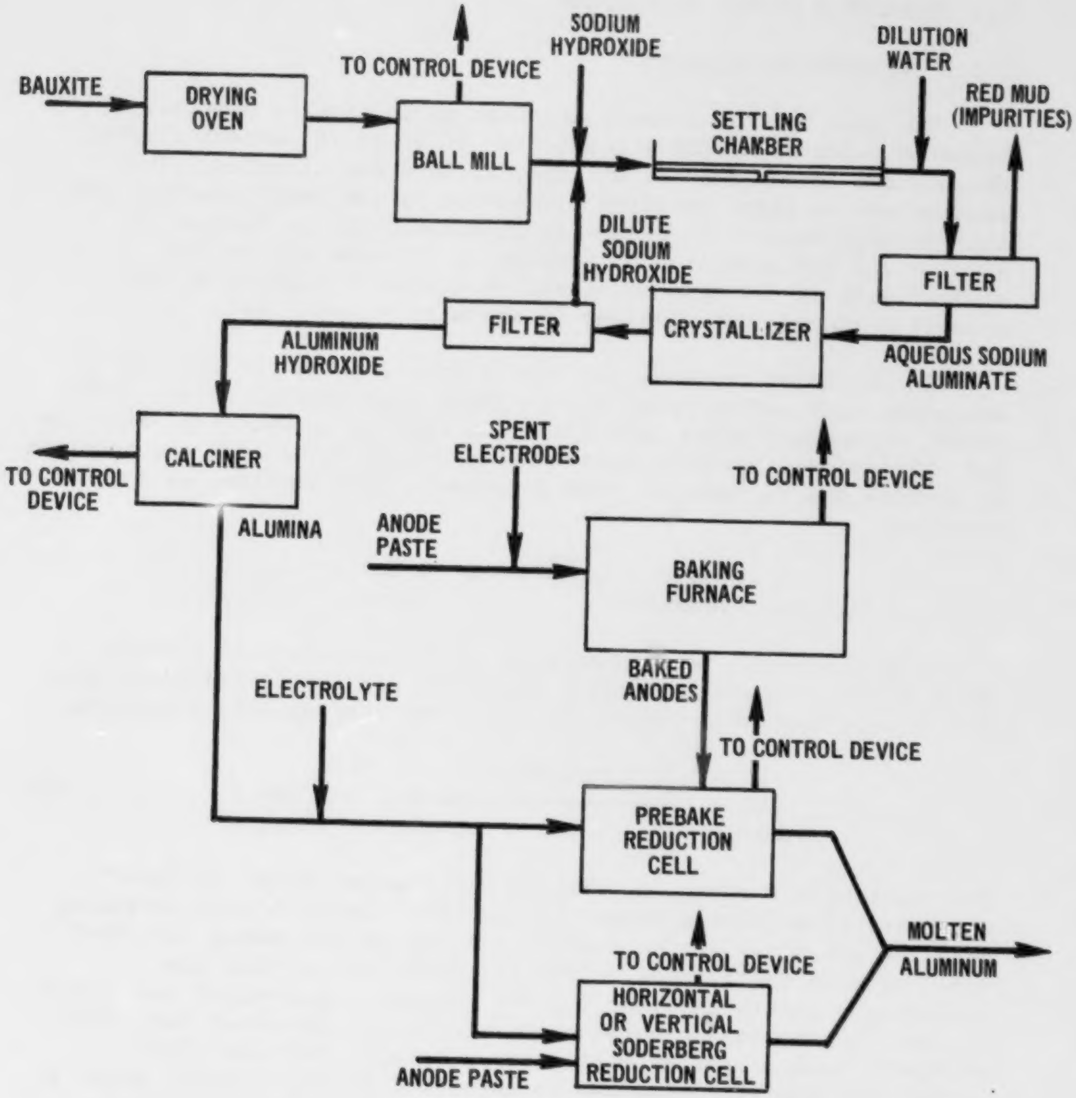
BAUXITE
DRYING OVEN
TO CONTROL DEVICE
BALL MILL
SODIUM HYDROXIDE
SETTLING CHAMBER
DILUTION WATER
RED MUD (IMPURITIES)
DILUTE SODIUM HYDROXIDE
FILTER
FILTER
CRYSTALLIZER
AQUEOUS SODIUM ALUMINATE
ALUMINUM HYDROXIDE
CALCINER
TO CONTROL DEVICE
ALUMINA
SPENT ELECTRODES
ANODE PASTE
TO CONTROL DEVICE
BAKING FURNACE
BAKED ANODES
ELECTROLYTE
TO CONTROL DEVICE
PREBAKE REDUCTION CELL
TO CONTROL DEVICE
MOLTEN ALUMINUM
HORIZONTAL OR VERTICAL SODERBERG REDUCTION CELL
ANODE PASTE

Figure 7.1-1. Schematic diagram of primary aluminum production process.

TABLE 7.1-1. RAW MATERIAL AND ENERGY REQUIREMENTS FOR ALUMINUM PRODUCTION

Parameter	Typical value
Cell operating temperature	~950°C (~1740°F)
Current through pot line	60,000 - 125,000 amperes
Voltage drop per cell	4.3 - 5.2
Current efficiency	85 - 90%
Energy required	13.2 - 18.7 kwh/kg aluminum (6.0 - 8.5 kwh/lb aluminum)
Weight alumina consumed	1.89 - 1.92 kg (lb) AL_2O_3/kg (lb) aluminum
Weight electrolyte fluoride consumed	0.03 - 0.10 kg (lb) fluoride/kg (lb) aluminum
Weight carbon electrode consumed	0.45 - 0.55 kg (lb) electrode/kg (lb) aluminum

Aluminum reduction cells are distinguished by the anode configuration used in the pots. Three types of pots are currently used, prebaked (PB), horizontal stud Soderberg (HSS), and vertical stud Soderberg (VSS). Most of the aluminum produced in the U. S. is processed in PB cells. These cells use anodes that are press formed from a carbon paste and baked in a direct fired ring furnace or indirect fired tunnel kiln. Volatile organic vapors from the coke and pitch paste comprising the anodes are emitted, and most are destroyed in the baking furnace. The baked anodes, typically 14 to 24 per cell, are attached to metal rods and serve as replaceable anodes.

In reduction, the carbon anodes are lowered into the cell and consumed at a rate of about 2.5 cm (1 in.) per day. Prebaked cells are preferred over Soderberg cells for their lower power requirements, reduced generation of volatile pitch vapors from the carbon anodes, and provision for better cell hooding to capture emissions.

The second most commonly used reduction cell is the horizontal stud Soderberg. This type of cell uses a "continuous" carbon anode. A green anode paste of pitch and coke is periodically added at the top of the superstructure and is baked by the heat of the cell to a solid mass as the material moves down the casing. The cell casing consists of aluminum sheeting and perforated steel channels, through which electrode connections or studs are inserted horizontally into the anode paste. During reduction, as the baking anode is lowered, the lower row of studs and the bottom channel are removed and the flexible electrical connectors are moved to a higher row. Heavy organics from the anode paste are added to the cell emissions. The heavy tars can cause plugging of ducts, fans and emission control equipment.

The vertical stud Soderberg cell is similar to the HSS cell, except that the studs are mounted vertically in the anode paste. Gases from the VSS cells can be ducted to gas burners and the tars and oils combusted. The construction of the VSS cell prevents the installation of an integral gas collection device, and hooding is restricted to a canopy or skirt at the base of the cell where the hot anode enters the cell bath.

7.1.2 Emissions and Controls[1-3,9]

Controlled and uncontrolled emission factors for sulfur oxides, fluorides and total particulates are presented in Table 7.1-2. Fugitive particulate and fluoride emission factors for reduction cells are also presented in this table.

Emissions from aluminum reduction processes consist primarily of gaseous hydrogen fluoride and particulate fluorides, alumina, carbon monoxide, hydrocarbons or organics, and sulfur dioxide from the reduction cells and the anode baking furnaces. Large amounts of particulates are also generated during the calcining of aluminum hydroxide, but the economic value of this dust is such that extensive controls have been employed to reduce emissions to relatively small quantities. Small amounts of particulates are emitted from the bauxite grinding and materials handling processes.

The source of fluoride emissions from reduction cells is the fluoride electrolyte, which contains cryolite, aluminum fluoride (AlF_3), and fluorspar (CaF_2). For normal operation, the weight, or "bath", ratio of sodium fluoride (NaF) to AlF_3 is maintained between 1.36 and 1.43 by the addition of Na_2CO_3, NaF and AlF_3. Experience has shown that increasing this ratio has the effect of decreasing total fluoride effluents. Cell fluoride emissions are also decreased by lowering the operating temperature and increasing the alumina content in the bath. Specifically, the ratio of gaseous (mainly hydrogen fluoride and silicon tetrafluoride) to particulate fluorides varies from 1.2 to 1.7 with PB and HSS cells, but attains a value of approximately 3.0 with VSS cells.

Particulate emissions from reduction cells consist of alumina and carbon from anode dusting, cryolite, aluminum fluoride, calcium fluoride, chiolite ($Na_5Al_3F_{14}$) and ferric oxide. Representative size distributions for particulate emissions from PB cells and HSS cells are presented in Table 7.1-3. Particulates less than 1 micron in diameter represent the largest fraction (35 - 44 percent) of uncontrolled emissions. Uncontrolled particulate emissions from one HSS cell had a mass mean particle diameter of 5.5 microns. Thirty percent by mass of the particles were submicron, and 16 percent were less than 0.2μ in diameter.[7]

TABLE 7.1-2. EMISSION FACTORS FOR PRIMARY ALUMINUM PRODUCTION PROCESSES[a]

EMISSION FACTOR RATING: A

Operation	Total Particulate[b] kg/Mg	Total Particulate[b] lb/ton	Gaseous Fluoride (HF) kg/Mg	Gaseous Fluoride (HF) lb/ton	Particulate Fluoride (F) kg/Mg	Particulate Fluoride (F) lb/ton	Sulfur Oxides kg/Mg	Sulfur Oxides lb/ton	References
Bauxite grinding									
Uncontrolled	3.0	6.0	Neg	Neg	NA	NA	NA	NA	1,3
Spray tower	0.9	1.8	Neg	Neg	NA	NA	NA	NA	1,3
Floating bed scrubber	0.85	1.7	Neg	Neg	NA	NA	NA	NA	1,3
Quench tower and spray screen	0.5	1.0	Neg	Neg	NA	NA	NA	NA	1,3
Electrostatic precipitator (ESP)	0.06	0.12	Neg	Neg	NA	NA	NA	NA	1,3
Aluminum hydroxide calcining									
Uncontrolled	100.0	200.0	Neg	Neg	NA	NA	NA	NA	1,3
Spray tower	30.0	60.0	Neg	Neg	NA	NA	NA	NA	1,3
Floating bed scrubber	28.0	56.0	Neg	Neg	NA	NA	NA	NA	1,3
Quench tower	17.0	34.0	Neg	Neg	NA	NA	NA	NA	1,3
ESP	2.0	4.0	Neg	Neg	NA	NA	NA	NA	1,3
Anode baking furnace									
Uncontrolled	1.5	3.0	0.45	0.9	0.05	0.1	0.7-2	1.4-4	2,9
Fugitive	NA	NA	NA	NA	NA	NA	NA	NA	
Spray tower	0.375	0.75	0.02	0.04	0.015	0.03	NA	NA	9
ESP	0.375	0.75	0.02	0.04	0.015	0.03	NA	NA	2
Dry alumina scrubber	0.03	0.06	0.0045	0.009	0.001	0.002	NA	NA	2,9
Prebake cell									
Uncontrolled	47.0	94.0	12.0	24.0	10.0	20.0	30.0[c]	60.0[c]	1,2,9
Fugitive	2.5	5.0	0.6	1.2	0.5	1.0	NA	NA	2,9
Emissions to collector	44.5	89.0	11.4	22.8	9.5	19.0	NA	NA	2
Multiple cyclones	9.8	19.6	11.4	22.8	2.1	4.2	NA	NA	2
Dry alumina scrubber	0.9	1.8	0.1	0.2	0.2	0.4	NA	NA	2,9
Dry ESP + spray tower	2.25	4.5	0.7	1.4	1.7	3.4	NA	NA	2,9
Spray tower	8.9	17.8	0.7	1.4	1.9	3.8	NA	NA	2
Floating bed scrubber	8.9	17.8	0.25	0.5	1.9	3.8	NA	NA	2
Coated bag filter dry scrubber	0.9	1.8	1.7	3.4	0.2	0.4	NA	NA	2
Cross flow packed bed	13.15	26.3	3.35	6.7	2.8	5.6	NA	NA	9
Dry + secondary scrubber	0.35	0.7	0.2	0.4	0.15	0.3	NA	NA	9

TABLE 7.1-2 (cont.) EMISSION FACTORS FOR PRIMARY ALUMINUM PRODUCTION PROCESSES[a]

EMISSION FACTOR RATING: A

Operation	Total Particulate[b]		Gaseous Fluoride (HF)		Particulate Fluoride (F)		Sulfur Oxides		References
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	
Vertical Soderberg stud cell									
Uncontrolled	39.0	78.0	16.5	33.0	5.5	11.0	NA	NA	2,9
Fugitive	6.0	12.0	2.45	4.9	0.85	1.7	NA	NA	9
Emissions to collector	33.0	66.0	14.05	28.1	4.65	9.3	NA	NA	9
Spray tower	8.25	16.5	0.15	0.3	1.15	2.3	NA	NA	2
Venturi scrubber	1.3	2.6	0.15	0.3	0.2	0.4	NA	NA	2
Multiple cyclones	16.5	33.0	14.05	28.1	2.35	4.7	NA	NA	2
Dry alumina scrubber	0.65	1.3	0.15	0.3	0.1	0.2	NA	NA	2
Scrubber + wet ESP + spray screen + scrubber	3.85	7.7	0.75	1.5	0.65	1.3	NA	NA	2,9
Horizontal Soderberg stud cell									
Uncontrolled	49.0	98.0	11.0	22.0	6.0	12.0	NA	NA	2,9
Fugitive	5.0	10.0	1.1	2.2	0.6	1.2	NA	NA	2,9
Emissions to collector	44.0	88.0	9.9	19.8	5.4	10.8	NA	NA	2,9
Spray tower	11.0	22.0	3.75	7.5	1.35	2.7	NA	NA	2,9
Floating bed scrubber	9.7	19.4	0.2	0.4	1.2	2.4	NA	NA	2
Scrubber + wet ESP	0.9	1.8	0.1	0.2	0.1	0.2	NA	NA	2,9
Wet ESP	0.9	1.8	0.5	1.0	0.1	0.2	NA	NA	9
Dry alumina scrubber	0.9	1.8	0.2	0.4	0.1	0.2	NA	NA	9

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[a] For bauxite grinding, expressed as kg/Mg (lb/ton) of bauxite processed. For calcining of aluminum hydroxide, expressed as kg/Mg (lb/ton) of alumina produced. All other factors per Mg (ton) of molten aluminum product. Emission factors for sulfur oxides have C ratings. NA = Information not available.

[b] Includes particulate fluorides.

[c] Reference 2. Estimates for SO_x based on 3% sulfur in coke.

Emissions from reduction cells also include hydrocarbons or organics, carbon monoxide and sulfur oxides. Small amounts of hydrocarbons are released by PB pots, and larger amounts are emitted from HSS and VSS pots. In vertical cells, these organics are incinerated in integral gas burners. Sulfur oxides originate from sulfur in the anode coke and pitch. The concentrations of sulfur oxides in VSS cell emissions range from 200 to 300 ppm. Emissions from PB plants usually have SO_2 concentrations ranging from 20 to 30 ppm.

TABLE 7.1-3. REPRESENTATIVE PARTICLE SIZE DISTRIBUTIONS OF UNCONTROLLED EMISSIONS FROM PREBAKED AND HORIZONTAL STUD SODERBERG CELLS[a]

Size range (μ)	Particles (wt %)	
	PB	HSS
<1	35	44
1 to 5	25	26
5 to 10	8	8
10 to 20	5	6
20 to 44	5	4
>44	22	12

[a] Reference 1.

Emissions from anode bake ovens include the products of fuel combustion, high boiling organics from the cracking, distillation and oxidation of paste binder pitch, sulfur dioxide from the carbon paste, fluorides from recycled anode butts, and other particulate matter. The concentrations of uncontrolled emissions of SO_2 from anode baking furnaces range from 5 to 47 ppm (based on 3 percent sulfur in coke).[8]

Casting emissions are mainly fumes of aluminum chloride, which may hydrolyze to HCl and Al_2O_3.

A variety of control devices has been used to abate emissions from reduction cells and anode baking furnaces. To control gaseous and particulate fluorides and particulate emissions, one or more types of wet scrubbers (spray tower and chambers, quench towers, floating beds, packed beds, venturis, and self induced sprays) have been applied to all three types of reduction cells and to anode baking furnaces. Also, particulate control methods such as electrostatic precipitators (wet and dry), multiple cyclones and dry alumina scrubbers (fluid bed, injected, and coated filter types) have been employed with baking furnaces and on all three cell types. Also, the alumina adsorption systems are being used on all three cell types for controlling both gaseous and particulate fluorides by passing the pot offgases through the entering alumina feed, on which the fluorides are absorbed. This technique has an overall control efficiency of 98 to 99 percent. Baghouses are then used to collect residual fluorides entrained in the alumina and to recycle them to the reduction cells. Wet electrostatic precipitators approach adsorption in particulate removal efficiency but must be coupled to a wet scrubber or coated baghouse to catch hydrogen fluoride.

Scrubber systems also remove a portion of the SO_2 emissions. These emissions could be reduced by wet scrubbing or by reducing the quantity of sulfur in the anode coke and pitch, i.e., calcinating the coke.

In the aluminum hydroxide calcining, bauxite grinding and materials handling operations, various dry dust collection devices such as centrifugal collectors, multiple cyclones, or electrostatic precipitators and/or wet scrubbers have been used.

Potential sources of fugitive particulate emissions in the primary aluminum industry are bauxite grinding, materials handling, anode baking and the three types of reduction cells (see Table 7.1-2). These fugitives probably have particle size distribution similar to those presented in Table 7.1-3.

References for Section 7.1

1. Engineering and Cost Effectiveness Study of Fluoride Emissions Control, Vol. I, APTD-0945, U.S. Environmental Protection Agency, Research Triangle Park, NC, January 1972.

2. Air Pollution Control in the Primary Aluminum Industry, Vol. I, EPA-450/3-73-004a, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1973.

3. Particulate Pollutant System Study, Vol. I, APTD-0743, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1971.

4. Emissions from Wet Scrubbing System, Report Number Y-7730-E, York Research Corp., Stamford, CT, May 1972.

5. Emissions from Primary Aluminum Smelting Plant, Report Number Y-7730-B, York Research Corp., Stamford, CT, June 1972.

6. Emissions from the Wet Scrubber System, Report Number Y-7730-F, York Research Corp., Stamford, CT, June 1972.

7. T.R. Hanna and M.J. Pilat, "Size Distribution of Particulates Emitted from a Horizontal Spike Soderberg Aluminum Reduction Cell", JAPCA, 22:533-536, July 1972.

8. Background Information for Standards of Performance: Primary Aluminum Industry, Volume 1: Proposed Standards, EPA 450/2-74-020a, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1974.

9. Primary Aluminum: Guidelines for Control of Fluoride Emissions from Existing Primary Aluminum Plants, EPA-450/2-78-049b, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1979.

7.8 SECONDARY ALUMINUM OPERATIONS

7.8.1 General

Secondary aluminum operations involve the cleaning, melting, refining and pouring of aluminum recovered from scrap. The processes used to convert scrap aluminum to secondary aluminum products such as lightweight metal alloys for industrial castings and ingots are presented in Figure 7.8-1. Production involves two general classes of operation, scrap treatment and smelting/refining.

Scrap treatment involves receiving, sorting and processing scrap to remove contaminants and to prepare the material for smelting. Processes based on mechanical, pyrometallurgical and hydrometallurgical techniques are used, and those employed are selected to suit the type of scrap processed.

The smelting/refining operation generally involves the following steps:

- charging
- melting
- fluxing
- alloying
- mixing
- demagging
- degassing
- skimming
- pouring

All of these steps may be involved in each operation, with process distinctions being in the furnace type used and in emission characteristics. However, as with scrap treatment, not all of these steps are necessarily incorporated into the operations at a particular plant. Some steps may be combined or reordered, depending on furnace design, scrap quality, process inputs and product specifications.

Scrap treatment - Purchased aluminum scrap undergoes inspection upon delivery. Clean scrap requiring no treatment is transported to storage or is charged directly into the smelting furnace. The bulk of the scrap, however, must be manually sorted as it passes along a steel belt conveyor. Free iron, stainless steel, zinc, brass and oversized materials are removed. The sorted scrap then goes to appropriate scrap treating processes or is charged directly to the smelting furnace.

Sorted scrap is conveyed to a ring crusher or hammer mill, where the material is shredded and crushed, with the iron torn away from the aluminum. The crushed material is passed over vibrating screens to remove dirt and fines, and tramp iron is removed by magnetic drums and/or belt separators. Baling equipment compacts bulky aluminum scrap into 1 x 2 meter (3 x 6 foot) bales.

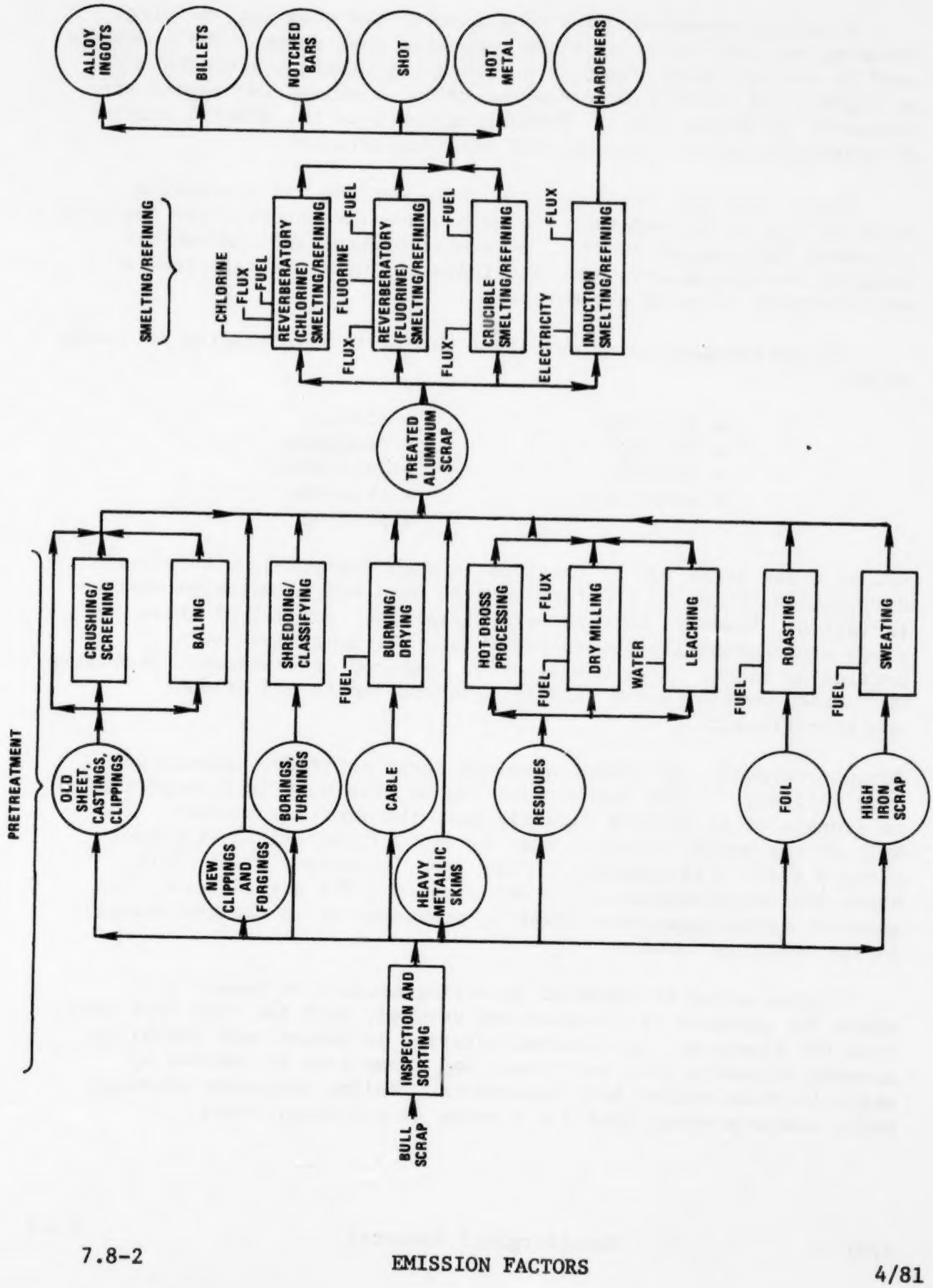
PRETREATMENT
BULL SCRAP
INSPECTION AND SORTING
OLD SHEET, CASTINGS, CLIPPINGS
NEW CLIPPINGS AND FORGINGS
BORINGS, TURNINGS
CABLE
HEAVY METALLIC SKIMS
RESIDUES
FOIL
HIGH IRON SCRAP
CRUSHING/ SCREENING
BALING
SHREDDING/ CLASSIFYING
FUEL
BURNING/ DRYING
HOT DROSS PROCESSING
FUEL
FLUX
DRY MILLING
WATER
LEACHING
FUEL
ROASTING
FUEL
SWEATING
TREATED ALUMINUM SCRAP
SMELTING/REFINING
CHLORINE
FLUX
FUEL
REVERBERATORY (CHLORINE) SMELTING/REFINING
FLUX
FLUORINE
FUEL
REVERBERATORY (FLUORINE) SMELTING/REFINING
FLUX
FUEL
CRUCIBLE SMELTING/REFINING
ELECTRICITY
FLUX
INDUCTION SMELTING/REFINING
ALLOY INGOTS
BILLETS
NOTCHED BARS
SHOT
HOT METAL
HARDENERS

Figure 7.8-1. Process flow diagram for the secondary aluminum processing industry.

Pure aluminum cable with steel reinforcement or insulation is cut by alligator type shears and granulated or further reduced in hammer mills, to separate the iron core and the plastic coating from the aluminum. Magnetic processing accomplishes iron removal, and air classification separates the insulation.

Borings and turnings, in most cases, are treated to remove cutting oils, greases, moisture and free iron. The processing steps involved are (a) crushing in hammer mills or ring crushers, (b) volatilizing the moisture and organics in a gas or oil fired rotary dryer, (c) screening the dried chips to remove aluminum fines, (d) removing iron magnetically and (e) storing the clean dried borings in tote boxes.

Aluminum can be recovered from the hot dross discharged from a refining furnace by batch fluxing with a salt/cryolite mixture in a mechanically rotated, refractory lined barrel furnace. The metal is tapped periodically through a hole in its base. Secondary aluminum recovery from cold dross and other residues from primary aluminum plants is carried out by means of this batch fluxing in a rotary furnace. In the dry milling process, cold aluminum laden dross and other residues are processed by milling, screening and concentrating to obtain a product containing at least 60-70 percent aluminum. Ball, rod or hammer mills can be used to reduce oxides and nonmetallics to fine powders. Separation of dirt and other unrecoverables from the metal is achieved by screening, air classification and/or magnetic separation.

Leaching involves (a) wet milling, (b) screening, (c) drying and (d) magnetic separation to remove fluxing salts and other non-recoverables from drosses, skimmings and slags. First, the raw material is fed into a long rotating drum or an attrition or ball mill where soluble contaminants are leached. The washed material is then screened to remove fines and dissolved salts and is dried and passed through a magnetic separator to remove ferrous materials. The nonmagnetics then are stored or charged directly to the smelting furnace.

In the roasting process, carbonaceous materials associated with aluminum foil are charred and then separated from the metal product.

Sweating is a pyrometallurgical process used to recover aluminum from high iron content scrap. Open flame reverberatory furnaces may be used. Separation is accomplished as aluminum and other low melting constituents melt and trickle down the hearth, through a grate and into air cooled molds or collecting pots. This product is termed "sweated pig". The higher melting materials, including iron, brass and oxidation products formed during the sweating process, are periodically removed from the furnace.

Smelting/refining - In reverberatory (chlorine) operations, reverberatory furnaces are commonly used to convert clean sorted scrap, sweated pigs or some untreated scrap to specification ingots, shot or hot metal. The scrap is first charged to the furnace by some mechanical means, often through charging wells designed to permit introduction of chips and light scrap below the surface of a previously melted charge ("heel"). Batch processing is generally practiced for alloy ingot production, and continuous feeding and pouring are generally used for products having less strict specifications.

Cover fluxes are used to prevent air contact with and consequent oxidation of the melt. Solvent fluxes react with nonmetallics such as burned coating residues and dirt to form insolubles which float to the surface as part of the slag.

Alloying agents are charged through the forewell in amounts determined by product specifications. Injection of nitrogen or other inert gases into the molten metal can be used to aid in raising dissolved gases (typically hydrogen) and intermixed solids to the surface.

Demagging reduces the magnesium content of the molten charge from approximately 0.3 to 0.5 percent (typical scrap value) to about 0.1 percent (typical product line alloy specification). When demagging with chlorine gas, chlorine is injected under pressure through carbon lances to react with magnesium and aluminum as it bubbles to the surface. Other chlorinating agents, or fluxes, are sometimes used, such as anhydrous aluminum chloride or chlorinated organics.

In the skimming step, contaminated semisolid fluxes (dross, slag or skimmings) are ladled from the surface of the melt and removed through the forewell. The melt is then cooled before pouring.

The reverberatory (fluorine) process is similar to the reverberatory (chlorine) smelting/refining process, except that aluminum fluoride (AlF_3) is employed in the demagging step instead of chlorine. The AlF_3 reacts with magnesium to produce molten metal aluminum and solid magnesium fluoride salt which floats to the surface of the molten aluminum and is skimmed off.

The crucible smelting/refining process is used to melt small batches of aluminum scrap, generally limited to 500 kg (1000 lb) or less. The metal treating process steps are essentially the same as those of reverberatory furnaces.

The induction smelting/refining process is designed to produce hardeners by blending pure aluminum and hardening agents in an electric induction furnace. The process steps include charging scrap to the furnace, melting, adding and blending the hardening agent, skimming, pouring and casting into notched bars.

7.8.2 Emissions and Controls[1]

Table 7.8-1 presents emission factors for the principal emission sources in secondary aluminum operations. Although each step in scrap treatment and smelting/refining is a potential source of emissions, emissions from most of the processing operations are either not characterized here or emit only small amounts of pollutants.

Crushing/screening produces small amounts of metallic and nonmetallic dust. Baling operations produce particulate emissions, primarily dirt and alumina dust resulting from aluminum oxidation. Shredding/classifying also emits small amounts of dust. Emissions from these processing steps are normally uncontrolled.

Burning/drying operations emit a wide range of pollutants. Afterburners are used generally to convert unburned hydrocarbons to CO_2 and H_2O. Other gases potentially present, depending on the composition of the organic contaminants, include chlorides, fluorides and sulfur oxides. Oxidized aluminum fines blown out of the dryer by the combustion gases comprise particulate emissions. Wet scrubbers are sometimes used in place of afterburners.

Mechanically generated dust from the rotating barrel dross furnace constitutes the main air emission of hot dross processing. Some fumes are produced from the fluxing reactions. Fugitive emissions are controlled by enclosing the barrel in a hood system and by ducting the stream to a baghouse. Furnace offgas emissions, mainly fluxing salt fume, are controlled by a venturi scrubber.

In dry milling, large amounts of dust are generated from the crushing, milling, screening, air classification and materials transfer steps. Leaching operations may produce particulate emissions during drying. Emissions from roasting are particulates from the charring of carbonaceous materials.

Emissions from sweating furnaces vary with the feed scrap composition. Smoke may result from incomplete combustion of organic contaminants (e.g., rubber, oil and grease, plastics, paint, cardboard, paper) which may be present. Fumes can result from oxidation of magnesium and zinc contaminants and from fluxes in recovered drosses and skims.

Atmospheric emissions from reverberatory (chlorine) smelting/refining represent a significant fraction of the total particulate and gaseous effluents generated in the secondary aluminum industry. Typical furnace effluent gases contain combustion products, chlorine, hydrogen chloride and metal chlorides of zinc, magnesium and aluminum, aluminum oxide and various metals and metal compounds, depending on the quality of scrap charged. Particulate emissions from one secondary aluminum smelter have a size distribution of $D_{50} = 0.4\mu$.[3]

TABLE 7.8-1. PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS[a]

Operation	Uncontrolled		Baghouse		Electrostatic precipitator		Emission Factor Rating
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	
Sweating furnace[b]	7.25	14.5	1.65	3.3	-	-	C
Smelting							
Crucible furnace[b]	0.95	1.9	-	-	-	-	C
Reverberatory furnace[c]	2.15	4.3	0.65[e]	1.3[e]	0.65	1.3	B
Chlorination station[d]	500	1000	25	50	-	-	B

[a] Reference 2. Emission factors expressed as units per unit weight of metal processed. Factors apply only to Al metal recovery operations.
[b] Based on averages of two source tests.
[c] Based on averages of ten source tests. Standard deviation of uncontrolled emission factor is 17.5 kg/Mg (3.5 lb/ton), that of controlled factor is 0.15 kg/Mg (0.3 lb/ton).
[d] Expressed as kg/Mg (lb/ton) of chlorine used. Based on averages of ten source tests. Standard deviation of uncontrolled emission factor is 215 kg/Mg (430 lb/ton), of controlled factor, 18 kg/Mg (36 lb/ton).
[e] This factor may be lower if a coated baghouse is used.

Emissions from reverberatory (fluorine) smelting/refining are similar to those from reverberatory (chlorine) smelting/refining. The use of AlF_3 rather than chlorine in the demagging step reduces demagging emissions. Fluorides are emitted as gaseous fluorides (hydrogen fluoride, aluminum and magnesium fluoride vapors, and silicon tetrafluoride) or as dusts. Venturi scrubbers are usually used for fluoride emission control.

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1. W.M. Coltharp, et al., Multimedia Environmental Assessment of the Secondary Nonferrous Metal Industry, Draft Final Report, 2 vols., EPA Contract No. 68-02-1319, Radian Corporation, Austin, TX, June 1976.

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7.10 GRAY IRON FOUNDRIES

7.10.1 General[1]

Gray iron foundries produce gray iron castings by melting, alloying and molding pig iron and scrap iron. The process flow diagram of a typical gray iron foundry is presented in Figure 7.10-1. The four major processing operations of the typical gray iron foundry are raw materials handling, metal melting, mold and core production, and casting and finishing.

Raw Materials Handling - The raw material handling operations include the receiving, unloading, storage and conveying of all raw materials for the foundry. The raw materials used by gray iron foundries are pig iron, iron and steel scrap, foundry returns, metal turnings, alloys, carbon additives, coke, fluxes (limestone, soda ash, fluorspar, calcium carbide), sand, sand additives, and binders. These raw materials are received in ships, railcars, trucks and containers, transferred by truck, loaders and conveyers to both open piles and enclosed storage areas, and then transferred by similar means from storage to the processes.

Metal Melting - Generally the first step in the metal melting operations is scrap preparation. Since scrap is normally purchased in the proper size for furnace feed, scrap preparation primarily consists of scrap degreasing. This is very important for electric induction furnaces, as organics on scrap can cause an explosion. Scrap may be degreased with solvents, by centrifugation or by combustion in an incinerator or heater, or it may be charged without treatment, as is often the case with cupola furnaces. After preparation, the scrap, iron, alloy and flux are weighed and charged to the furnace.

The cupola furnace is the major type of furnace used in the gray iron industry today. It is typically a vertical refractory lined cylindrical steel shell, charged at the top with alternate layers of metal, coke and flux. Larger cupolas are water cooled instead of refractory lined. Air introduced at the bottom of the cupola burns the coke to melt the metal charge. Typical melting capacities range from 0.5 to 14 Mg (1 - 27 tons) per hour, with a few larger units approaching 50 Mg (100 tons) per hour. Cupolas can be tapped either continuously or intermittently from a side tap hole at the bottom of the furnace.

Electric arc furnaces, used to a lesser degree in the gray iron industry, are large refractory lined steel pots fitted with a refractory lined roof through which three graphite electrodes are inserted. The metal charge is heated to melting by electrical arcs produced by the current flowing between the electrodes and the charge. Electric arc furnaces are charged with raw material through the removed lid, by a chute through the lid, or through a door in

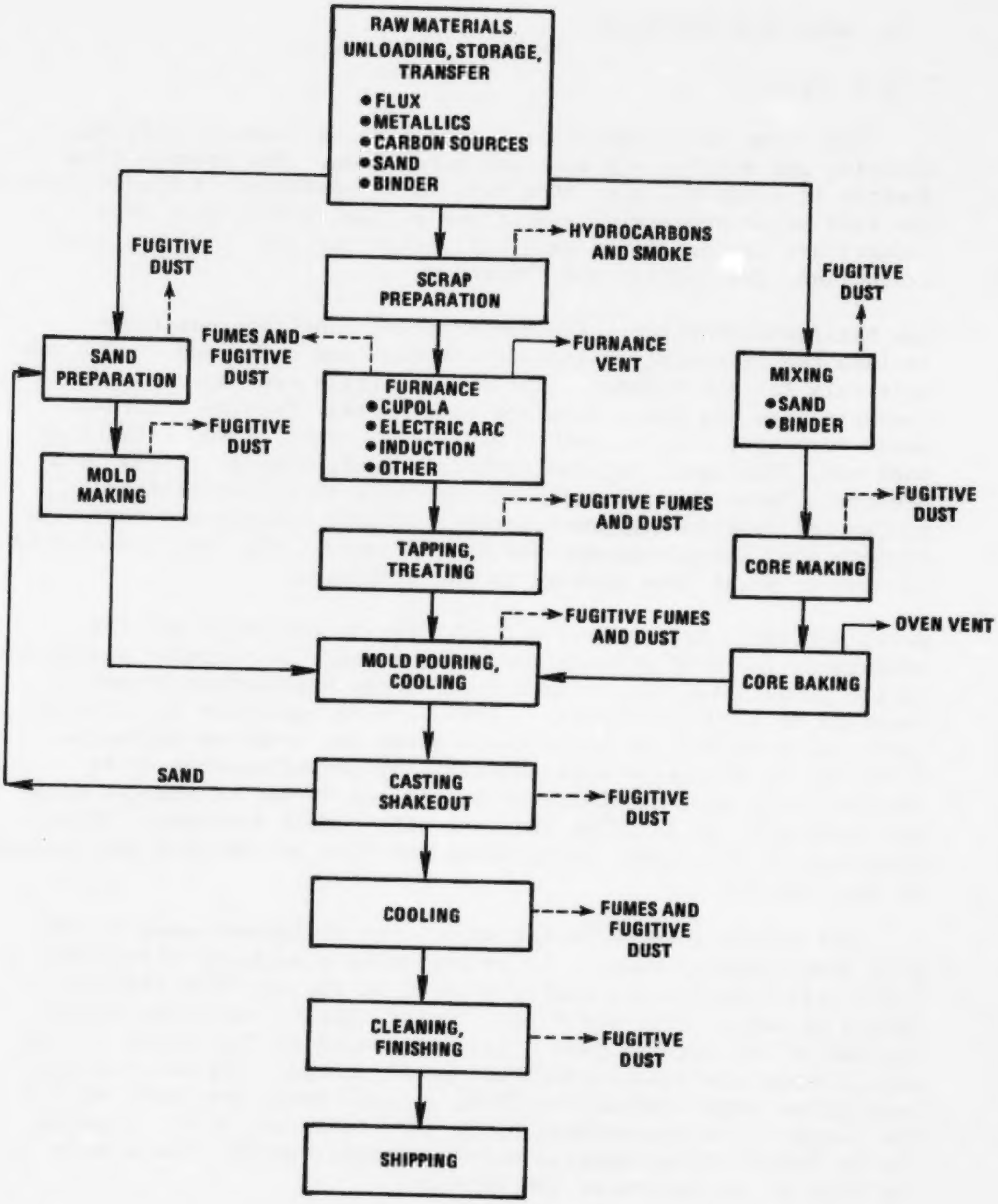
RAW MATERIALS
UNLOADING, STORAGE, TRANSFER
• FLUX
• METALLICS
• CARBON SOURCES
• SAND
• BINDER
HYDROCARBONS AND SMOKE
FUGITIVE DUST
SCRAP PREPARATION
FUGITIVE DUST
FUMES AND FUGITIVE DUST
FURNANCE VENT
SAND PREPARATION
FURNANCE
• CUPOLA
• ELECTRIC ARC
• INDUCTION
• OTHER
MIXING
• SAND
• BINDER
FUGITIVE DUST
MOLD MAKING
FUGITIVE FUMES AND DUST
FUGITIVE DUST
TAPPING, TREATING
CORE MAKING
FUGITIVE FUMES AND DUST
OVEN VENT
MOLD POURING, COOLING
CORE BAKING
SAND
CASTING SHAKEOUT
FUGITIVE DUST
COOLING
FUMES AND FUGITIVE DUST
CLEANING, FINISHING
FUGITIVE DUST
SHIPPING

Figure 7.10-1. Typical flow diagram of a grey iron foundry.

the side. The molten metal is tapped by tilting and pouring through a hole in the side. Melting capacities range up to 10 Mg (20 tons) per hour.

A third furnace type used in the gray iron industry is the electric induction furnace. Induction furnaces are vertical refractory lined cylinders surrounded by electrical coils energized with alternating current. The resulting fluctuating magnetic field heats the metal. Induction furnaces are kept closed except when charging, skimming and tapping. The molten metal is tapped by tilting and pouring through a hole in the side. Induction furnaces are also used with other furnaces to hold and superheat the charge after melting and refining in another furnace.

A small percentage of melting in the gray iron industry is also done in air furnaces, reverberatory furnaces, pot furnaces and indirect arc furnaces.

The basic melting process operations are 1) furnace charging, in which the metal, scrap, alloys, carbon and flux are added to the furnace, 2) melting, during which the furnace remains closed, 3) backcharging, which involves the addition of more metal and, possibly, alloys, 4) refining and treating, during which the chemistry is adjusted, 5) slag removing, and 6) tapping molten metal into a ladle or directly into molds.

Mold and Core Production - Cores are molded sand shapes used to make the internal voids in castings, and molds are forms used to shape the exterior of castings. Cores are made by mixing sand with organic binders, molding the sand into a core, and baking the core in an oven. Molds are prepared by using a mixture of wet sand, clay and organic additives to make the mold shapes, and then by drying with hot air. Increasingly, cold setting binders are being used in both core and mold production. Used sand from shakeout operations is recycled to the sand preparation area to be cleaned, screened and reused to make molds.

Casting and Finishing - When the melting process is complete, the molten metal is tapped and poured into a ladle. At this point, the molten metal may be treated by addition of magnesium to produce ductile iron by the addition of soda ash or lime to remove sulfur. At times, graphite may be innoculated to adjust carbon levels. The treated molten metal is then poured into molds and allowed partially to cool. The partially cooled castings are placed on a vibrating grid where the mold and core sand is shaken away from the casting. The sand is returned to the mold manufacturing process, and the castings are allowed to cool further in a cooling tunnel.

In the cleaning and finishing process, burrs, risers and gates are broken off or ground off to match the contours of the castings, after which the castings are shot blasted to remove remaining mold sand and scale.

TABLE 7.10-1. EMISSION FACTORS FOR GRAY IRON FURNACES[a]

EMISSION FACTOR RATING: B

Furnace Type	Particulates		Carbon Monoxide		Sulfur Dioxide		Nitrogen Oxides		VOC		Lead[b]	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Cupola[c,d]												
Uncontrolled	8.5 (3-17)[e]	17 (5-34)[e]	145[f]	73[f]	0.6S[g]	1.25S[g]	-	-	-	-	0.05-0.6	0.1-1.1
Wet cap	4	8	-	-	-	-	-	-	-	-	-	-
Impingement scrubber	2.5	5	-	-	-	-	-	-	-	-	-	-
High energy scrubber	0.4	0.8	-	-	0.3S[g]	0.6S[g]	-	-	-	-	-	-
Electrostatic precipitator	0.3	0.6	-	-	-	-	-	-	-	-	-	-
Bag filter	0.1	0.2	-	-	-	-	-	-	-	-	-	-
Electric Arc[h]	5 (3-10)[e]	10 (5-20)[e]	0.5-19	1-37	neg	neg	.02-.3	.04-.6	.03-.15	.06-.3	-	-
Electric Induction[c]	0.75	1.5	neg	neg	neg	neg	-	-	-	-	.005-.05	.009-0.1
Reverberatory[c]	1	2	-	-	-	-	-	-	-	-	.006-.07	.012-0.14

[a] Expressed as weight of pollutant per weight of gray iron produced. Neg = negligible.
[b] References 4 and 9-12.
[c] References 2-5.
[d] Approximately 85% of the total charge is metal. For every unit weight of coke in the charge, 7 units of gray iron are produced.
[e] Values in parentheses represent the range of expected values.
[f] Reference 6.
[g] Reference 1. S represents % sulfur in the coke. This factor assumes 30% of the sulfur is converted to SO_2.
[h] References 1 and 8.

TABLE 7.10-2. EMISSION FACTORS FOR FUGITIVE PARTICULATES FROM GRAY IRON FOUNDRIES[a]

EMISSION FACTOR RATING: D

Process	Emissions		Emitted to Work Environment		Emitted to Atmosphere	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Scrap and Charge Handling, Heating[b]	0.3	0.6	0.25	0.5	0.1	0.2
Magnesium Treatment[b]	2.5	5	2.5	5	0.5	1
Innoculation[c]	1.5 - 2.5	3 - 5	-	-	-	-
Pouring[b]	2.5	5	2.5	5	1	2
Cooling[b]	5	10	4.5	9	0.5	1
Shakeout[b]	16	32	6.5	13	0.5	1
Cleaning, Finishing[b]	8.5	17	0.15	0.3	0.05	0.1
Sand Handling, Preparation, Mulling[b]	20	40	13	26	1.5	3
Core Making, Baking[b]	0.6	1.1	0.6	1.1	0.6	1.1

[a] Expressed as weight of pollutant per weight of metal melted.

[b] Reference 1, p. III-13.

[c] Reference 7, p. 2-83.

7.10.2 Emissions and Controls[1]

Emissions from the raw materials handling operations consist of fugitive particulates generated from the receiving, unloading, storage and conveying of all raw materials for the foundry. These emissions are controlled by enclosing the major emission points and routing the air from the enclosures through fabric filters or wet collectors.

Scrap preparation using heat will emit smoke, organics and carbon monoxide, and preparation using solvent degreasers will emit organics. (See Section 4.6, Solvent Degreasing.) Catalytic incinerators and afterburners can be applied to control about 95 percent of the organics and carbon monoxide.

Emissions from melting furnaces consist of particulates, carbon monoxide, organics, sulfur dioxide, nitrogen oxides and small quantities of chlorides and fluorides. The particulates, chlorides and fluorides are generated by flux, incomplete combustion of coke, carbon additives, and dirt and scale on the scrap charge. Organics on the scrap and the reactivity of the coke effect carbon monoxide emissions. Sulfur dioxide emissions, characteristic of cupola furnaces, are attributable to sulfur in the coke.

The highest concentration of furnace emissions occurs during charging, backcharging, alloying, slag removal, and tapping operations, when the furnace lids and doors are opened. Generally, these emissions have escaped into the furnace building and have been vented through roof vents. Controls for emissions during the melting and refining operations usually concern venting the furnace gases and fumes directly to a collection and control system. Controls for fugitive furnace emissions involve the use of roof hoods or special hoods in the proximity of the furnace doors, and of tapping ladles to capture emissions and to route them to emission control systems.

High energy scrubbers and bag filters with respective efficiencies greater than 95 percent and 98 percent are used to control particulate emissions from cupolas and electric arc furnaces in the U.S. Afterburners achieving 95 percent control are used for reducing organics and carbon monoxide emissions from cupolas. Normally, induction furnaces are uncontrolled.

The major pollutants from mold and core production are particulates from sand reclaiming, sand preparation, sand mixing with binders and additives, and mold and core forming. There are organics, CO and particulate emissions from core baking, and organic emissions from mold drying. Bag filters and high energy scrubbers can be used to control particulates from mold and core production. Afterburners and catalytic incinerators can be used to control organics and carbon monoxide emissions.

TABLE 7.10-3. SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM THREE ELECTRIC ARC FURNACE INSTALLATIONS[a]

Particle Size (μ)	Foundry A	Foundry B	Foundry C
<1	5	8	18
<2	15	54	61
<5	28	80	84
<10	41	89	91
<15	55	93	94
<20	68	96	96
<50	98	99	99

[a] Reference 1, p. III-39.

TABLE 7.10-4. SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM EIGHTEEN CUPOLA FURNACE INSTALLATIONS[a]

Particle Size (μ)	Cumulative % Less Than Indicated Size
<2	14
<5	24
<10	34
<20	44
<50	61
<100	78
<200	93

[a] Reference 1, p. III-33.

In the casting operations, large quantities of particulates can be generated in the treating and innoculation steps before pouring. Emissions from pouring consist of fumes, carbon monoxide, organics, and particulates evolved from the mold and core materials when contacted with molten iron. These emissions continue to evolve as the mold cools. A significant quantity of particulate emissions is also generated during the casting shakeout operation. Particulate emissions from shakeout can be controlled by either high energy scrubbers or bag filters. Emissions from pouring are normally uncontrolled or are ducted into other exhaust streams.

Emissions from finishing operations are of large particulates emitted during the removal of burrs, risers and gates, and during the blasting process. Particulates from finishing operations are usually large in size and are easily controlled by cyclones.

Emission factors for melting furnaces are presented in Table 7.10-1, and emission factors for fugitive particulates are presented in Table 7.10-2. Typical particle size distributions for emissions from electric arc and cupola furnaces are presented in Table 7.10-3 and Table 7.10-4.

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1. J.A. Davis, et al., Screening Study on Cupolas and Electric Furnaces in Gray Iron Foundries, EPA Contract No. 68-01-0611, Battelle Laboratories, Columbus, OH, August 1975.

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11. Emission Test No. 71-CI-27, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1972.

12. Emission Test No. 71-CI-30, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

Table 7.11-1. EMISSION FACTORS FOR SECONDARY LEAD PROCESSING[a]

Source	Particulates		Lead		Sulfur Dioxide		Emission Factor Rating
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	
Battery breaking[b]	NA	NA	NA	NA	NA	NA	---
Crushing[b]	NA	NA	NA	NA	NA	NA	---
Sweating[b]	32-70	16-35	7-16[c]	4-8[c]	NA	NA	E
Leaching[b]	Neg	Neg	Neg	Neg	Neg	Neg	---
Smelting[d]							
Reverberatory	147 (56-313)[e]	74 (28-157)[e]	34 (13-72)[c]	17 (6-36)[c]	80 (71-88)[e]	40 (36-44)[e]	B
Blast (cupola)[d]	193 (21-381)[f]	97 (11-191)[f]	44 (5-88)[c]	22 (2-44)[c]	53 (18-110)[f]	27 (9-55)[f]	B
Kettle refining	0.8[g]	0.4[g]	0.2[c]	0.1[c]	NA	NA	B
Oxidation[h]							
Kettle	<40[i]	<20[i]	NA	NA	NA	NA	E
Reverberatory	NA	NA	NA	NA	NA	NA	---

[a] All emission factors are based on the quantity of material charged to the furnace (except particulate kettle oxidation). NA = data not available. Neg = negligible.

[b] Reference 1.

[c] Emission factor rating of E. Emission factors for lead emissions are based on an approximation that particulate emissions contain 23% lead. References 3 and 5.

[d] Numbers in parentheses represent ranges of values obtained.

[e] References 8 - 11.

[f] References 11 - 13.

[g] Reference 11.

[h] References 1 and 2.

[i] Essentially all of the product lead oxide is entrained in an air stream and subsequently recovered by a baghouse with average collection efficiencies in excess of 99%. The reported value represents emissions of lead oxide that escape a baghouse used to collect the lead oxide product. The emission factor is based on the amount of lead oxide produced and represents an approximate upper limit for emissions.

Table 7.11-4. PARTICLE SIZE DISTRIBUTION OF PARTICULATES RECOVERED FROM A COMBINED BLAST AND REVERBERATORY FURNACE GAS STREAM WITH BAGHOUSE CONTROL[a]

Particle Size Range, μm	Fabric filter catch, wt %
0 to 1	13.3
1 to 2	45.2
2 to 3	19.1
3 to 4	14.0
4 to 16	8.4

[a] Reference 4, Table 86.

References for Section 7.11

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7.13 STEEL FOUNDRIES

7.13.1 Process Description[1]

Steel foundries produce steel castings by the melting, alloying and molding of pig iron and steel scrap. The process flow diagram of a typical steel foundry is presented in Figure 7.13-1. The major processing operations of the typical steel foundry are raw materials handling, metal melting, mold and core production, and casting and finishing.

Raw Materials Handling - The raw material handling operations include the receiving, unloading, storage and conveying of all raw materials for the foundry. Some of the raw materials used by steel foundries are pig iron, iron and steel scrap, foundry returns, metal turnings, alloys, carbon additives, fluxes (limestone, soda ash, fluorspar, calcium carbide), sand, sand additives, and binders. These raw materials are received in ships, railcars, trucks, and containers, and are transferred by trucks, loaders, and conveyors to both open pile and enclosed storage areas. They are then transferred by similar means from storage to the subsequent processes.

Metal Melting - Generally, the first step in the metal melting operations is scrap preparation. Since scrap is normally purchased in the proper size for furnace feed, preparation primarily consists of scrap degreasing. This is very important for electric induction furnaces, as organics on scrap can be explosive. Scrap may be degreased with solvents, by centrifugation or by incinerator or preheater combustion. After preparation, the scrap, metal, alloy, and flux are weighed and charged to the furnace.

Electric arc furnaces are used almost exclusively in the steel foundry for melting and formulating steel. Electric arc furnaces are large refractory lined steel pots, fitted with a refractory roof through which three graphite electrodes are inserted. The metal charge is melted with resistive heating generated by electrical current flowing among the electrodes and through the charge. Electric arc furnaces are charged with raw materials by removing the lid, through a chute opening in the lid, or through a door in the side. The molten metal is tapped by tilting and pouring through a hole in the side. Melting capacities range up to 10 megagrams (11 tons) per hour.

A second, less common, furnace used in steel foundries is the open hearth furnace, a very large shallow refractory lined vessel which is operated in a batch manner. The open hearth furnace is fired at alternate ends, using the heat from the waste combustion gases to heat the incoming combustion air.

A third furnace used in the steel foundry is the induction furnace. Induction furnaces are vertical refractory lined cylinders

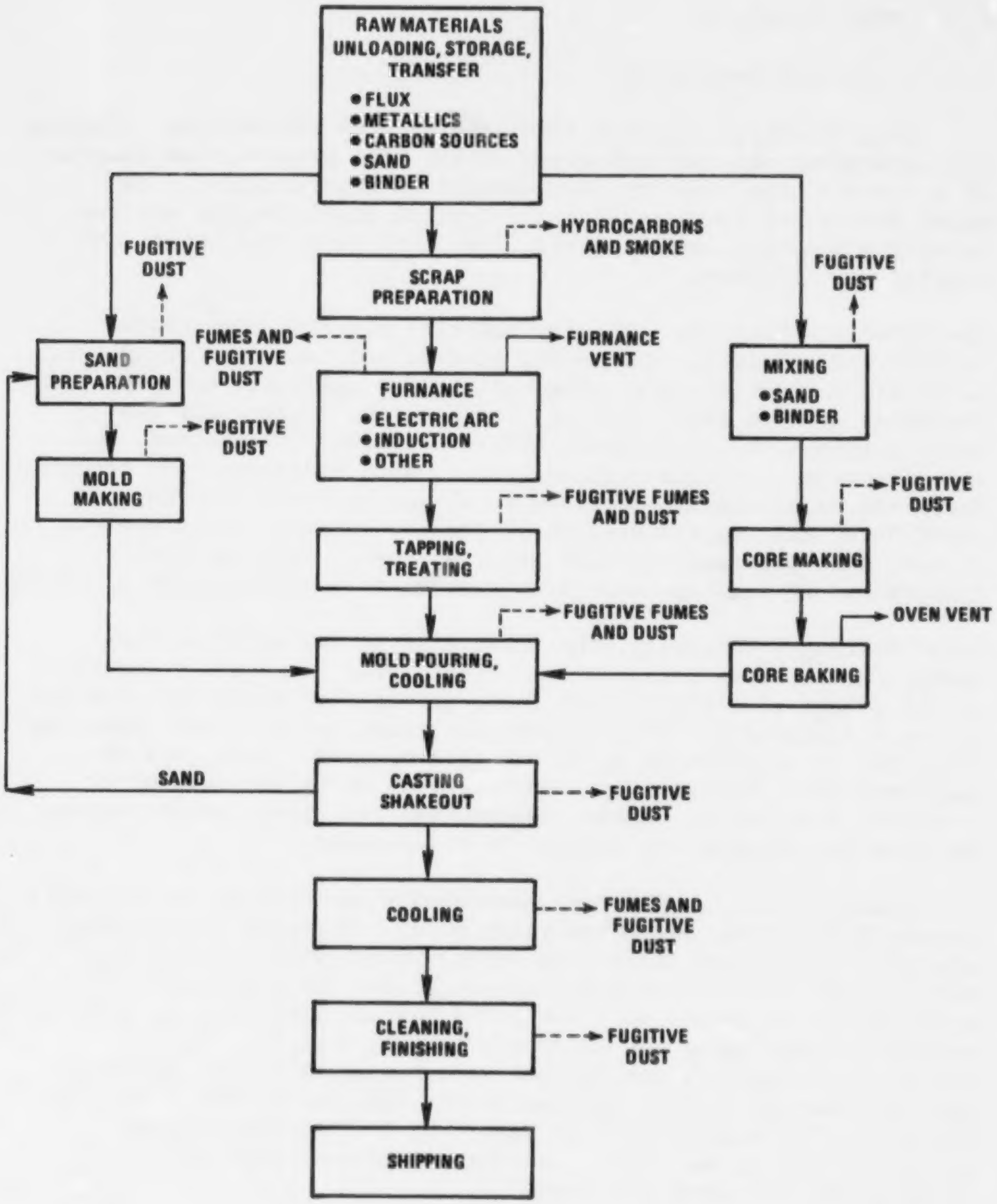
RAW MATERIALS UNLOADING, STORAGE, TRANSFER
• FLUX
• METALLICS
• CARBON SOURCES
• SAND
• BINDER
HYDROCARBONS AND SMOKE
SCRAP PREPARATION
FUGITIVE DUST
FUGITIVE DUST
SAND PREPARATION
FUMES AND FUGITIVE DUST
FURNANCE VENT
MIXING
• SAND
• BINDER
FURNANCE
• ELECTRIC ARC
• INDUCTION
• OTHER
FUGITIVE DUST
MOLD MAKING
FUGITIVE DUST
FUGITIVE FUMES AND DUST
TAPPING, TREATING
CORE MAKING
FUGITIVE FUMES AND DUST
OVEN VENT
MOLD POURING, COOLING
CORE BAKING
SAND
CASTING SHAKEOUT
FUGITIVE DUST
COOLING
FUMES AND FUGITIVE DUST
CLEANING, FINISHING
FUGITIVE DUST
SHIPPING

Figure 7.13-1. Typical flow diagram of a steel foundry.

surrounded by electrical coils energized with alternating current. The resulting fluctuating magnetic field heats the metal. Induction furnaces are kept closed except when charging, skimming and tapping. The molten metal is tapped by tilting and pouring through a hole in the side. Induction furnaces are also used with other furnaces, to hold and superheat a charge melted and refined in the other furnaces. A very small fraction of the secondary steel industry also uses crucible and pneumatic converter furnaces.

The basic melting process operations are 1) furnace charging, in which metal, scrap, alloys, carbon, and flux are added to the furnace, 2) melting, during which the furnace remains closed, 3) backcharging, which is the addition of more metal and possibly alloys, 4) refining, during which the carbon content is adjusted, 5) oxygen lancing, which is injecting oxygen into the molten steel to dislodge slag and to adjust the chemistry of the metal, 6) slag removal, and 7) tapping the molten metal into a ladle or directly into molds.

Mold and Core Production - Cores are forms used to make the internal voids in castings, and molds are forms used to shape the casting exterior. Cores are made of sand with organic binders, molded into a core and baked in an oven. Molds are made of wet sand with clay and organic additives, dried with hot air. Increasingly, coal setting binders are being used in both core and mold production. Used sand from castings shakeout operations is recycled to the sand preparation area, where it is cleaned, screened and reused.

Casting and Finishing - When the melting process is complete, the molten metal is tapped and poured into a ladle. At this time, the molten metal may be treated by adding alloys and/or other chemicals. The treated metal is then poured into molds and is allowed partially to cool under carefully controlled conditions. Molten metal may be poured directly from the furnace to the mold.

When partially cooled, the castings are placed on a vibrating grid, and the sand of the mold and core are shaken away from the casting. The sand is recycled to the mold manufacturing process, and the casting is allowed to cool further.

In the cleaning and finishing process, burrs, risers and gates are broken or ground off to match the contour of the casting. Afterward, the castings are usually shot blasted to remove remaining mold sand and scale.

7.13.2 Emissions and Controls[1]

Emissions from the raw materials handling operations are fugitive particulates generated from receiving, unloading, storage and conveying all raw materials for the foundry. These emissions are controlled by enclosing the major emission points and routing the air from the enclosures through fabric filters.

Emissions from scrap preparation consist of hydrocarbons if solvent degreasing is used, and consist of smoke, organics and carbon monoxide if heating is used. Catalytic incinerators and afterburners of approximately 95 percent control efficiency for carbon monoxide and organics can be applied to these sources.

Emissions from melting furnaces are particulates, carbon monoxide, organics, sulfur dioxide, nitrogen oxides, and small quantities of chlorides and fluorides. The particulates, chlorides and fluorides are generated by the flux, the carbon additives, and dirt and scale on the scrap charge. Organics on the scrap and the carbon additives effect CO emissions. The highest concentrations of furnace emissions occur during charging, backcharging, alloying, oxygen lancing, slag removal, and tapping operations, when the furnace lids and doors are opened. Characteristically, these emissions have escaped into the furnace building and have been vented through roof vents. Controls for emissions during the melting and refining operations focus on venting the furnace gases and fumes directly to an emission collection duct and control system. Controls for fugitive furnace emissions involve either the use of building roof hoods or of special hoods near the furnace doors, to collect emissions and route them to emission control systems. Emission control systems commonly used to control particulate emissions from electric arc and induction furnaces are bag filters, cyclones and venturi scrubbers. The capture efficiencies of the collection systems, presented in Table 7.13-1, range from 80 to 100 percent. Usually, induction furnaces are uncontrolled.

The major pollutants from mold and core production are particulates from sand reclaiming, sand preparation, sand mixing with binders and additives, and mold and core forming. There are volatile organics (VOC), CO and particulate emissions from core baking, and VOC emissions from mold drying. Bag filters and high energy scrubbers can be used to control particulates from mold and core production. Afterburners and catalytic incinerators can be used to control VOC and CO emissions.

In the casting operations, large quantities of particulates can be generated in the steps prior to pouring. Emissions from pouring consist of fumes, CO, VOC, and particulates from the mold and core materials when contacted by the molten steel. As the mold cools, emissions continue. A significant quantity of particulate emissions is also generated during the casting shakeout operation. The particulate emissions from the shakeout operations can be controlled by either high efficiency cyclones or bag filters. Emissions from pouring are usually uncontrolled.

Emissions from finishing operations consist of large particulates from the removal of burrs, risers and gates, and during shot blasting. Particulates from finishing operations typically are large and are generally controlled by cyclones.

TABLE 7.13-1. EMISSION FACTORS FOR STEEL FOUNDRIES

EMISSION FACTOR RATING: A

Process	Particulates[a]		Nitrogen oxides	
	kg/Mg	lb/ton	kg/Mg	lb/ton
Melting				
Electric arc[b,c]	6.5 (2 to 20)	13 (4 to 40)	0.1	0.2
Open hearth[d,e]	5.5 (1 to 10)	11 (2 to 20)	0.005	0.01
Open hearth oxygen lanced[f,g]	5 (4 to 5.5)	10 (8 to 11)	-	-
Electric induction[h]	0.05	0.1	-	-

[a] Expressed as units per unit weight of metal processed. If the scrap metal is very dirty or oily, or if increased oxygen lancing is employed, the emission factor should be chosen from the high side of the factor range.

[b] Electrostatic precipitator, 92 - 98% control efficiency; baghouse (fabric filter), 98 - 99% control efficiency; venturi scrubber, 94 - 98% control efficiency.

[c] References 2 - 10.

[d] Electrostatic precipitator, 95 - 98.5% control efficiency; baghouse, 99.9% control efficiency; venturi scrubber, 96 - 99% control efficiency.

[e] References 2, 11 - 13.

[f] Electrostatic precipitator, 95 - 98% control efficiency; baghouse, 99% control efficiency; venturi scrubber, 95 - 98% control efficiency.

[g] References 6 and 14.

[h] Usually not controlled.

Emission factors for melting furnaces in the steel foundry are presented in Table 7.13-1.

Although no emission factors are available for nonfurnace emission sources in steel foundries, they are very similar to those in iron foundries.[1] Nonfurnace emission factors and particle size distributions for iron foundry emission sources are presented in Section 7.10, Gray Iron Foundries.

References for Section 7.13

1. Paul F. Fennelly and Peter D. Spawn, Air Pollutant Control Techniques for Electric Arc Furnaces in the Iron and Steel Foundry Industry, EPA-450/2-78-024, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1978.

2. J.J. Schueneman, et al., Air Pollution Aspects of the Iron and Steel Industry, National Center for Air Pollution Control, Cincinnati, OH, June 1963.

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8. C.A. Faist, "Electric Furnace Steel", Proceedings of the American Institute of Mining and Metallurgical Engineers, 11:160-161, 1953.

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10. I.H. Douglas, "Direct Fume Extraction and Collection Applied to a Fifteen Ton Arc Furnace", Special Report on Fume Arrestment, Iron and Steel Institute, 1964, pp. 144, 149.

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14. D.W. Coy, Unpublished data, Resources Research, Incorporated, Reston, VA.

7.14 SECONDARY ZINC PROCESSING

7.14.1 Process Description[1,2]

The secondary zinc industry processes obsolete and scrap materials to recover zinc as slabs, dust and zinc oxide. Processing involves three operations, scrap pretreatment, melting and refining. Processes typically used in each operation are shown in Figure 7.14-1. Molten product zinc may be used in zinc galvanizing.

Scrap Pretreatment - Pretreatment is the partial removal of metal and other contaminants from scrap containing zinc. Sweating separates zinc from high melting metals and contaminants by melting the zinc in kettle, rotary, reverberatory, muffle or electric resistance furnaces. The product zinc then is usually directly used in melting, refining or alloying processes. The high melting residue is periodically raked from the furnace and further processed to recover zinc values. These residues may be processed by crushing/screening to recover impure zinc or by sodium carbonate leaching to produce zinc oxide.

In crushing/screening, zinc bearing residues are pulverized or crushed to break the physical bonds between metallic zinc and contaminants. The impure zinc is then separated in a screening or pneumatic classification step.

In sodium carbonate leaching, the zinc bearing residues are converted to zinc oxide, which can be reduced to zinc metal. They are crushed and washed to leach out zinc from contaminants. The aqueous stream is then treated with sodium carbonate, precipitating zinc as the hydroxide or carbonate. The precipitate is then dried and calcined to convert zinc hydroxide into crude zinc oxide. The ZnO product is usually refined to zinc at primary zinc smelters.

Melting - Zinc is melted at 425-590°C (800-1100°F) in kettle, crucible, reverberatory and electric induction furnaces. Zinc to be melted may be in the form of ingots, reject castings, flashing or scrap. Ingots, rejects and heavy scrap are generally melted first, to provide a molten bath to which light scrap and flashing are added. Before pouring, a flux is added and the batch agitated to separate the dross accumulating during the melting operation. The flux floats the dross and conditions it so it can be skimmed from the surface. After skimming, the melt can be poured into molds or ladles.

Refining/Alloying - Additional processing steps may involve alloying, distillation, distillation and oxidation, or reduction. Alloying produces mainly zinc alloys from pretreated scrap. Often the alloying operation is combined with sweating or melting.

Distillation retorts and furnaces are used to reclaim zinc from alloys or to refine crude zinc. Retort distillation is the

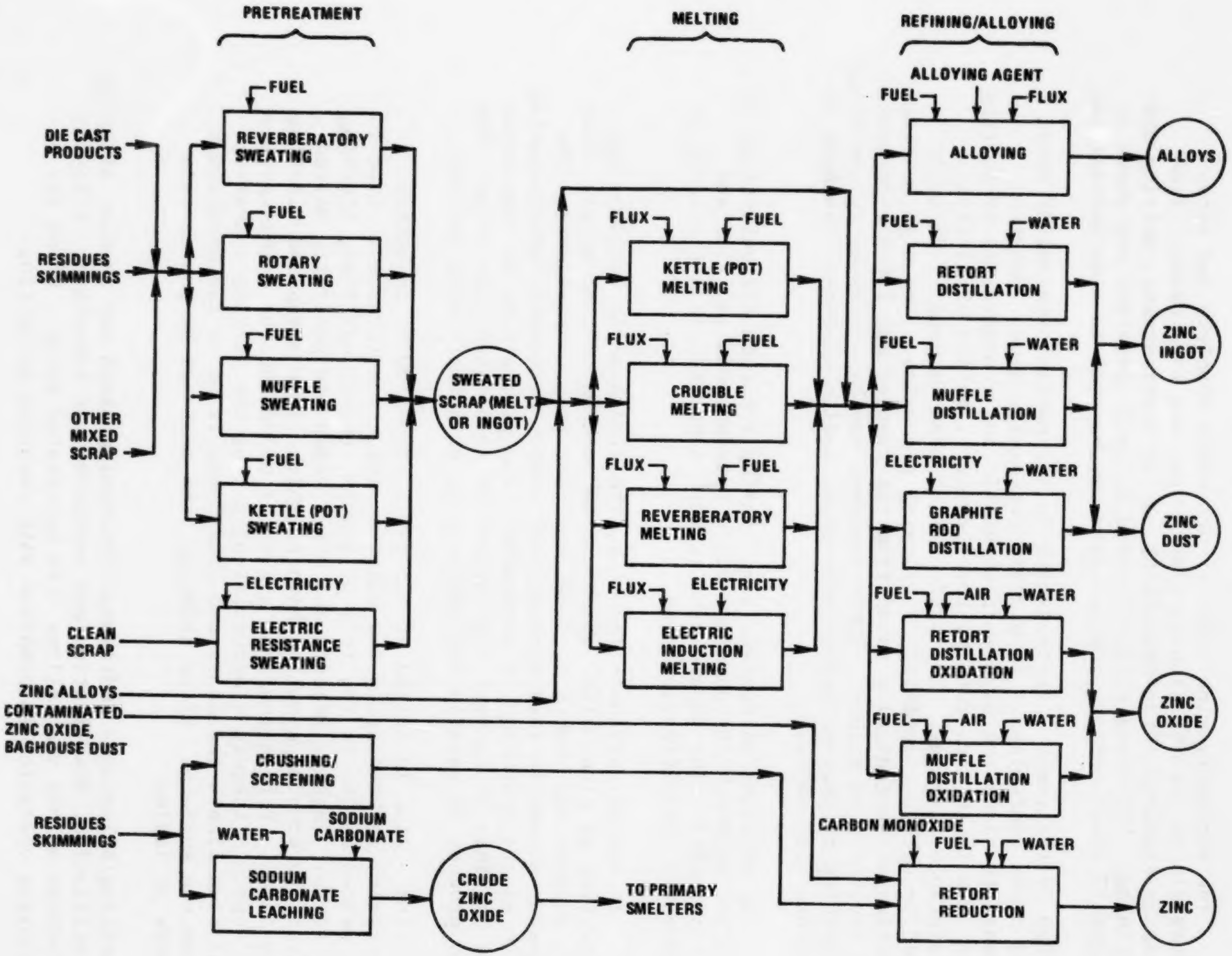
PRETREATMENT
MELTING
REFINING/ALLOYING
DIE CAST PRODUCTS
RESIDUES SKIMMINGS
OTHER MIXED SCRAP
CLEAN SCRAP
ZINC ALLOYS
CONTAMINATED ZINC OXIDE, BAGHOUSE DUST
RESIDUES SKIMMINGS
FUEL
REVERBERATORY SWEATING
FUEL
ROTARY SWEATING
FUEL
MUFFLE SWEATING
FUEL
KETTLE (POT) SWEATING
ELECTRICITY
ELECTRIC RESISTANCE SWEATING
CRUSHING/ SCREENING
WATER
SODIUM CARBONATE
SODIUM CARBONATE LEACHING
CRUDE ZINC OXIDE
TO PRIMARY SMELTERS
SWEATED SCRAP (MELT OR INGOT)
FLUX
FUEL
KETTLE (POT) MELTING
FLUX
FUEL
CRUCIBLE MELTING
FLUX
FUEL
REVERBERATORY MELTING
FLUX
ELECTRICITY
ELECTRIC INDUCTION MELTING
ALLOYING AGENT
FUEL
FLUX
ALLOYING
ALLOYS
FUEL
WATER
RETORT DISTILLATION
FUEL
WATER
MUFFLE DISTILLATION
ZINC INGOT
ELECTRICITY
WATER
GRAPHITE ROD DISTILLATION
ZINC DUST
FUEL
AIR
WATER
RETORT DISTILLATION OXIDATION
FUEL
AIR
WATER
MUFFLE DISTILLATION OXIDATION
ZINC OXIDE
CARBON MONOXIDE
FUEL
WATER
RETORT REDUCTION
ZINC

Figure 7.14-1. Process flow diagram of secondary zinc processing.

TABLE 7.14-1. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR SECONDARY ZINC SMELTING[a]

EMISSION FACTOR RATING: C

Operation	Emissions	
	kg/Mg	lb/ton
Reverberatory sweating[b]		
clean metallic scrap	Negligible	Negligible
general metallic scrap	6.5	13
residual scrap	16	32
Rotary sweating[c]	5.5-12.5	11-25
Muffle sweating[c]	5.4-16	10.8-32
Kettle sweating[b]		
clean metallic scrap	Negligible	Negligible
general metallic scrap	5.5	11
residual scrap	12.5	25
Electric resistance sweating[c]	<5	<10
Crushing/screening[c]	0.5-3.8	1.0-7.5
Sodium carbonate leaching		
crushing/screening[c]	0.5-3.8	1.0-7.5
calcining[d]	44.5	89
Kettle (pot) melting[d]	0.05	0.1
Crucible melting	DNA	DNA
Reverberatory melting	DNA	DNA
Electric induction melting	DNA	DNA
Alloying	DNA	DNA
Retort and muffle distillation		
pouring[c]	0.2-0.4	0.4-0.8
casting[c]	0.1-0.2	0.2-0.4
muffle distillation[d]	22.5	45
Graphite rod distillation[c,e]	Negligible	Negligible
Retort distillation/oxidation[f]	10-20	20-40
Muffle distillation/oxidation[f]	10-20	20-40
Retort reduction	23.5	47
Galvanizing[d]	2.5	5

[a] Expressed as units per unit weight of feed material processed for crushing/screening, skimming/residues processed; for kettle (pot) melting and retort and muffle distillation operations, metal product. Galvanizing factor expressed in units per unit weight of zinc used. DNA: Data not available.

[b] Reference 3.

[c] Reference 4.

[d] References 5-7.

[e] Reference 1.

[f] Reference 4. Factor units per unit weight of ZnO produced. The product zinc oxide dust is totally carried over in the exhaust gas from the furnace and is recovered with 98-99% efficiency.

vaporization at 980-1250°C (1800-2280°F) of elemental zinc with its subsequent condensation as zinc dust or liquid zinc. Rapid cooling of the vapor stream below the zinc melting point produces zinc dust, which can be removed from the condenser and packaged. If slab zinc is the desired product, the vapors are condensed slowly at a higher temperature. The resultant melt is cast into ingots or slabs. Muffle distillation furnaces produce principally zinc ingots, and graphite rod resistance distillation produces zinc dust.

Retort and muffle furnace distillation and oxidation processes produce zinc oxide dust. These processes are similar to distillation through the vaporization step. In contrast, for distillation/oxidation, the condenser is omitted, and the zinc vapor is discharged directly into an air stream leading to a refractory lined combustion chamber. Excess air is added to complete oxidation and to cool the product. The zinc oxide product is usually collected in a baghouse.

In retort reduction, zinc metal is produced by the reaction of carbon monoxide and zinc oxide to yield zinc and carbon dioxide. Carbon monoxide is supplied by the partial oxidation of the coke. The zinc is recovered by condensation.

Zinc Galvanizing - Zinc galvanizing is the coating of clean oxide free iron or steel with a thin layer of zinc by immersion in molten zinc. The galvanizing occurs in a vat or in dip tanks containing molten zinc and cover flux.

7.14.2 Emissions and Controls[1,2]

Factors for uncontrolled point source and fugitive particulate emissions are tabulated in Tables 7.14-1 and 7.14-2 respectively.

Emissions from sweating and melting operations consist principally of particulates, zinc fumes, other volatile metals, flux fumes and smoke generated by the incomplete combustion of grease, rubber and plastics in the zinc bearing feed material. Zinc fumes are negligible at low furnace temperatures, for they have a low vapor pressure even at 480°C (900°F). With elevated temperatures, however, heavy fuming can result. Flux emissions are minimized by the use of a nonfuming flux. Substantial emissions may arise from incomplete combustion of carbonaceous material in the zinc scrap. These contaminants are usually controlled by afterburners. Further emissions are the products of combustion of the furnace fuel. Since the furnace fuel is usually natural gas, these emissions are minor. In reverberatory furnaces, the products of fuel combustion are emitted with the other emissions. Other furnaces emit the fuel combustion products as a separate emission stream.

Particulates from sweating and melting are mainly hydrated $ZnCl_2$ and ZnO, with small amounts of carbonaceous material. Chemical

TABLE 7.14-2. FUGITIVE PARTICULATE UNCONTROLLED EMISSION FACTORS FOR SECONDARY ZINC SMELTING

EMISSION FACTOR RATING: E

Operation	Particulate	
	kg/Mg	lb/ton
Reverberatory sweating[b]	0.63	1.30
Rotary sweating[b]	0.45	0.90
Muffle sweating[b]	0.54	1.07
Kettle (pot) sweating[b]	0.28	0.56
Electric resistance sweating[b]	0.25	0.50
Crushing/screening[c]	2.13	4.25
Sodium carbonate leaching	DNA	DNA
Kettle (pot) melting furnace[b]	0.0025	0.005
Crucible melting furnace[d]	0.0025	0.005
Reverberatory melting furnace[b]	0.0025	0.005
Electric induction melting[b]	0.0025	0.005
Alloying retort distillation	DNA	DNA
Retort and muffle distillation	1.18	2.36
Casting[b]	0.0075	0.015
Graphite rod distillation	DNA	DNA
Retort distillation/oxidation	DNA	DNA
Muffle distillation/oxidation	DNA	DNA
Retort reduction	DNA	DNA

[a] Reference 8. Expressed as units per end product, except factors for crushing/screening and electric resistance furnaces, which are expressed as units per unit of scrap processed. DNA: Data not available.

[b] Estimate based on stack emission factor given in Reference 1, assuming fugitive emissions to be equal to 5% of stack emissions.

[c] Reference 1. Average of reported emission factors.

[d] Engineering judgement, assuming fugitive emissions from crucible melting furnace to be equal to fugitive emissions from kettle (pot) melting furnace.

analyses of particulate emissions from kettle sweat are shown in Table 7.14-3.

TABLE 7.14-3. COMPOSITION OF PARTICULATE EMISSIONS FROM KETTLE SWEAT PROCESSING[a]

Component	Percent
$ZnCl_2$	14.5 - 15.3
ZnO	46.9 - 50.0
NH_4Cl	1.1 - 1.4
Al_2O_3	1.0 - 2.7
Fe_2O_3	0.3 - 0.6
PbO	0.2
H_2O (in $ZnCl_2 \cdot 4H_2O$)	7.7 - 8.1
Oxide of Mg, Sn, Ni, Si, Ca, Na	2.0
Carbonaceous material	10.0
Moisture (deliquescent)	5.2 - 10.2

[a] Reference 3.

These particulates also contain Cu, Cd, Mn and Cr. Another analysis showed the following composition: 4 percent $ZnCl_2$, 77 percent ZnO, 4 percent H_2O, 4 percent metal chlorides and 10 percent carbonaceous matter.[4] These particulates vary widely in size. Particulates from kettle sweating of residual zinc scrap had the following size distributions:

60%	0 - 10μ
17%	11 - 20μ
23%	>20μ

Particulates from kettle sweating of metallic scrap had mean particle size distributions ranging from $D_{p50} = 1.1/\mu$ to $D_{p50} = 1.6\mu$.[3] Emissions from a reverberatory sweat furnace had an approximate $D_{p50} = 1\mu$.

Baghouses are most commonly used to recover particulate emissions from sweating and melting. In one application on a muffle sweating furnace, a cyclone and baghouse achieved particulate recovery efficiencies in excess of 99.7 percent.[4] In another application on a reverberatory sweating furnace, a baghouse removed 96.3 percent of the particulates, reducing the dust loading from 0.513 g/Nm^3 to 0.02 g/Nm^3.[2] Baghouses show similar efficiencies in removing particulates from exhaust gases of melting furnaces.

Crushing and screening operations are also sources of dust emissions. These particulates are composed of Zn, Al, Cu, Fe, Pb, Cd, Sn and Cr, and they can be recovered from hooded exhausts by baghouses.

The sodium carbonate leaching process produces particulate emissions of ZnO dust during the calcining operation. This dust can be recovered in baghouses, although $ZnCl_2$ in the dust may cause plugging problems.

Emissions from refining operations are mainly metallic fumes. These fume and dust particles are quite small, with sizes ranging from 0.05 - 1µ.[2] Distillation/oxidation operations emit their entire ZnO product in the exhaust gas. The ZnO has a very small particle size (0.03 to 0.5µ) and is recovered in baghouses with typical collection efficiencies of 98-99 percent.[4]

Some emissions of zinc oxide occur during galvanizing, but these emissions are small because of the bath flux cover and the relatively low temperature maintained in the bath.

Data describing the particle size distribution of fugitive emissions are unavailable. These emissions are probably similar in size to stack emissions.

References for Section 7.14

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2. John A. Danielson, Air Pollution Engineering Manual, 2nd Edition, AP-42, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1973. Out of Print.

3. W. Herring, Secondary Zinc Industry Emission Control Problem Definition Study (Part I), APTD-0706, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1971.

4. H. Nack, et al., Development of an Approach to Identification of Emerging Technology and Demonstration Opportunities, EPA-650/2-74-048, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1974.

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8. MINERAL PRODUCTS INDUSTRY

This section involves the processing and production of various minerals. Mineral processing is characterized by particulate emissions in the form of dust. Frequently, as in the case of crushing and screening, this dust is identical to the material being handled. Emissions also occur through handling and storing the finished product because this material is often dry and fine. Particulate emissions from some of the processes such as quarrying, yard storage, and dust from transport are difficult to control. Most of the emissions from the manufacturing processes discussed in this section, however, can be reduced by conventional particulate control equipment such as cyclones, scrubbers, and fabric filters. Because of the wide variety in processing equipment and final product, emissions cover a wide range; however, average emission factors have been presented for general use.

8.1 ASPHALTIC CONCRETE PLANTS

8.1.1 General

Asphaltic concrete (asphaltic hot mix) is a paving material which consists of a combination of graded aggregate that is dried, heated and evenly coated with hot asphalt cement.

Asphalt hot mix is produced by mixing hot, dry aggregate with hot liquid asphalt cement, in batch or continuous processes. Since different applications require different aggregate size distributions, the aggregate is segregated by size and is proportioned into the mix as required. In 1975, about 90 percent of total U.S. production was conventional batch process, and most of the remainder was continuous batch. The dryer drum process, another method of hot mix asphalt production, in which wet aggregate is dried and mixed with hot liquid asphalt cement simultaneously in a dryer, comprised less than 3 percent of the total, but most new construction favors this design. Plants may be either permanent or portable.

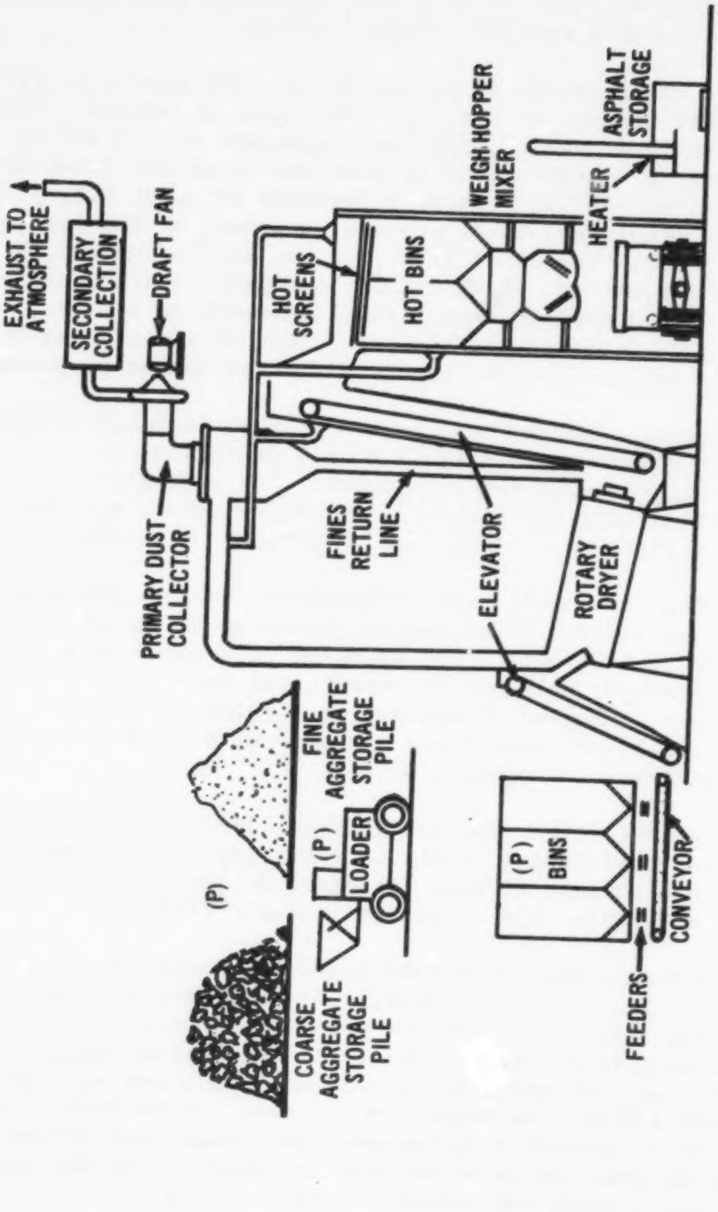
Conventional Plants - Conventional plants produce finished asphaltic concrete through either batch (Figure 8.1-1) or continuous (Figure 8.1-2) aggregate mixing operations. Raw aggregate is normally stockpiled near the plant, at a location where the moisture content will stabilize to between 3 and 5 percent by weight.

As processing for either type of operation begins, the aggregate is hauled from the storage piles and is placed in the appropriate hoppers of the cold feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a gas or oil fired rotary dryer. Because a substantial portion of the heat is transferred by radiation, dryers are equipped with flights designed to tumble the aggregate to promote drying.

As it leaves the dryer, the hot material drops into a bucket elevator and is transferred to a set of vibrating screens, where it is classified into as many as four different grades (sizes). The classified hot materials then enter the mixing operation.

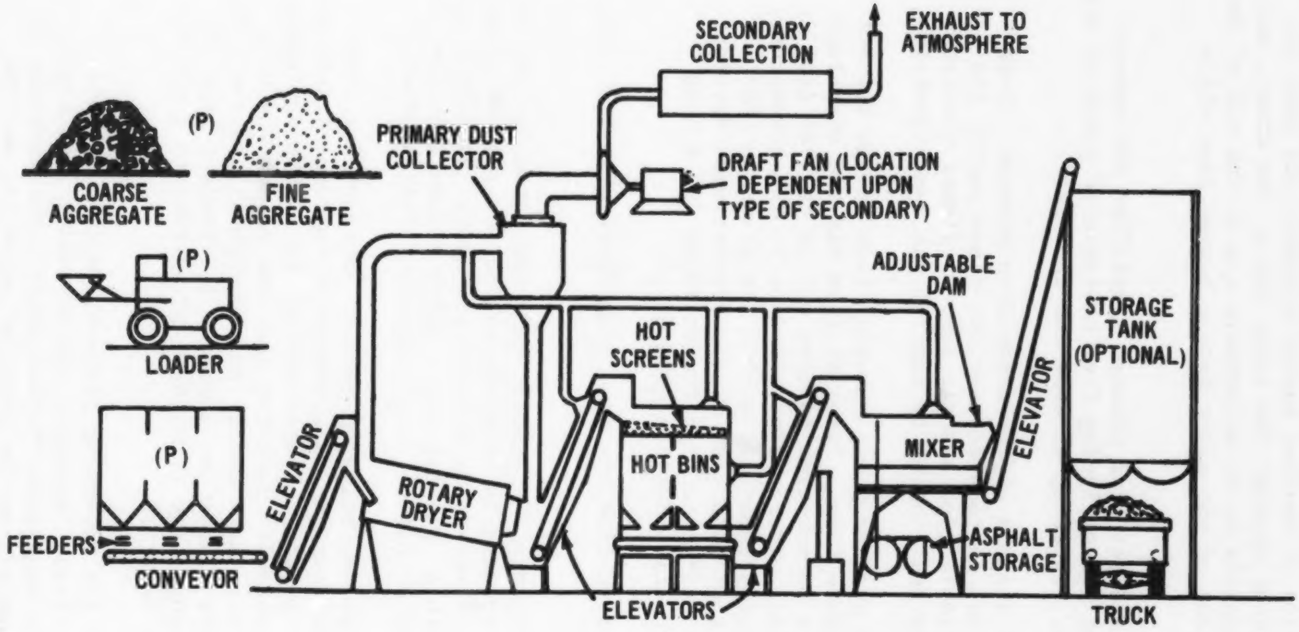
In a batch plant, the classified aggregate drops into one of four large bins. The operator controls the aggregate size distribution by opening individual bins and allowing the classified aggregate to drop into a weigh hopper until the desired weight is obtained. After all the material is weighed, the sized aggregates are dropped into a mixer and mixed dry for about 30 seconds. The asphalt, a solid at ambient temperatures, is pumped from heated storage tanks, weighed and injected into the mixer. The hot mix is then dropped into a truck and hauled to the job site.

In a continuous plant, the classified aggregate drops into a set of small bins which collect and meter the classified aggregate to the mixer. From the hot bins, the aggregate is metered through



EXHAUST TO ATMOSPHERE
SECONDARY COLLECTION
DRAFT FAN
PRIMARY DUST COLLECTOR
HOT SCREENS
HOT BINS
WEIGH HOPPER MIXER
ASPHALT STORAGE
HEATER
FINES RETURN LINE
ELEVATOR
ROTARY DRYER
FINE AGGREGATE STORAGE PILE
(P)
(P)
LOADER
COARSE AGGREGATE STORAGE PILE
(P)
BINS
CONVEYOR
FEEDERS

8.1-1. Batch hot mix asphalt plant. "P" denotes particulate emission points.[1]


SECONDARY
COLLECTION
EXHAUST TO
ATMOSPHERE
(P)
PRIMARY DUST
COLLECTOR
DRAFT FAN (LOCATION
DEPENDENT UPON
TYPE OF SECONDARY)
COARSE
AGGREGATE
FINE
AGGREGATE
(P)
LOADER
ADJUSTABLE
DAM
STORAGE
TANK
(OPTIONAL)
HOT
SCREENS
(P)
ELEVATOR
ROTARY
DRYER
HOT BINS
MIXER
ELEVATOR
FEEDERS
CONVEYOR
ASPHALT
STORAGE
ELEVATORS
TRUCK

8.1 2. Continuous hot-mix asphalt plant. "P" denotes particulate emission points.[1]

a set of feeder conveyors to another bucket elevator and into the mixer. Asphalt is metered through the inlet end of the mixer, and retention time is controlled by an adjustable dam at the end of the mixer. The mix flows out of the mixer into a hopper from which trucks are loaded.

Dryer Drum Plants - The dryer drum process simplifies the conventional process by using proportioning feed controls in place of hot aggregate storage bins, vibrating screens and the mixer.

Figure 8.1-3 is a diagram of the dryer drum process. Both aggregate and asphalt are introduced near the flame end of the revolving drum. A variable flow asphalt pump is linked electronically to the aggregate belt scales to control mix specifications.

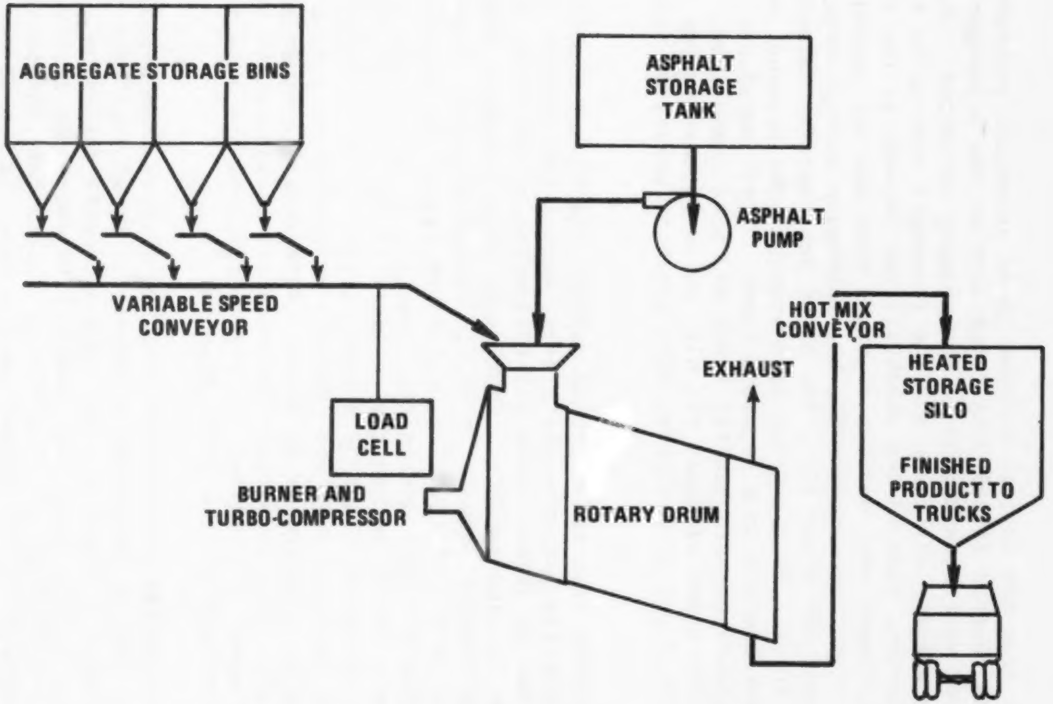
Dryer drum plants generally use parallel flow design for hot burner gases and aggregate flow. Parallel flow has the advantage of giving the mixture a longer time to coat and to collect dust in the mix, thereby reducing particulate emissions to the atmosphere. The amount of particulates generated within the dryer in this process is lower than that generated within conventional dryers, but because asphalt is heated to high temperatures for a long period of time, organic emissions are greater.

The mix is discharged from the revolving dryer drum into surge bins or storage silos.

Recycle Process for Drum Mix[22] - Asphalt injected directly into the dryer in the drum mix process is uniquely suited for the new, fast developing technology of recycling asphalt pavement. Many drum mix plants are now sold with a "recycle kit", which allows the plant to be converted to process blends of virgin and recycled material.

In a recycling process, salvaged asphalt pavement (or base material) that has been crushed and screened is introduced into the dryer drum at a point somewhere downstream of the virgin aggregate inlet. The amount of recycled pavement that can be successfully processed has not yet been determined, but eventually, as the technology is developed, the blends may approach 100 percent recycled material. Current blends range from about 20 percent to a maximum of 50 percent recycled material.

The advantages of the recycling process are that blended recycled material and virgin aggregate are generally less expensive than 100 percent virgin aggregate, liquid asphalt requirements are less due to residual asphalt in the recycled material, and the recycled material requires less drying than the virgin aggregate. The chief problem with recycling is opacity standards, because of emissions of blue smoke (an aerosol of submicron organic droplets volatilized from the asphalt and subsequently condensed before exiting the stack). However, current recycle plant designs have


AGGREGATE STORAGE BINS
ASPHALT STORAGE TANK
ASPHALT PUMP
VARIABLE SPEED CONVEYOR
HOT MIX CONVEYOR
EXHAUST
HEATED STORAGE SILO
LOAD CELL
FINISHED PRODUCT TO TRUCKS
BURNER AND TURBO-COMPRESSOR
ROTARY DRUM

8.1-3. Shearer type dryer-drum hot asphalt plant.

reduced blue smoke emissions greatly by preventing direct contact of flame and liquid asphalt as it is injected.

8.1.2 Emissions and Controls

Emission points at batch, continuous and drum dryer hot mix asphalt plants numbered below refer to Figures 8.1-1, 2 and 3, respectively.

Emissions from the various sources in an asphaltic concrete plant are vented either through the dryer vent or the scavenger vent. The dryer vent stream goes to the primary collector. The outputs of the primary collector and the scavenger vent go to the secondary collector, then to the stack (1) for release to the atmosphere. The scavenger vent carries releases from the hot aggregate elevator (5), vibrating screens (5), hot aggregate storage bins (5), weigh hopper and mixer (2). The dryer vent carries emissions only from the dryer. In the dryer drum process, the screens, weigh hopper and mixer are not in a separate tower. Dryer emissions in conventional plants contain mineral fines and fuel combustion products, and the mixer assembly (2) also emits materials from the hot asphalt. In dryer drum plants, both types of emissions arise in the drum.

Emissions from drum mix recycled asphalt plants are similar to emissions from regular drum mix plants, except for greater volatile organics due to direct flame volatilization of petroleum derivatives contained in used asphalt. Control of liquid organic emissions in the drum mix recycle process is by (1) introduction of recycled material at the center of the drum or farther toward the discharge end, coupled with a flight design that causes a dense curtain of aggregate between the flame and the residual asphalt, (2) protection of the material from the flame by a heat shield, or (3) insulation of the recycled material from the combustion zone entirely by a drum-within-a-drum arrangement in which virgin material is dried and coated in the inner drum, recycled material is indirectly heated in the annular space surrounding the inner drum, and the materials are mixed at discharge of the inner drum.[22]

Potential fugitive particulate emission sources from asphaltic concrete plants include unloading of aggregate to storage bins (5), conveying aggregate by elevators (5), and aggregate screening operations (5). Another source of particulate emissions is the mixer (2), which, although it is generally vented into the secondary collector, is open to the atmosphere when a batch is loaded onto a truck. This is an intermittent operation, and ambient conditions (wind, etc.) are quite variable, so these emissions are best regarded as fugitive. The open truck (4) can also be a source of fugitive VOC emissions, as can the asphalt storage tanks (3), which may also emit small amounts of polycyclics.

Thus, fugitive particulate emissions from hot mix asphalt plants are mostly dust from aggregate storage, handling and transfer. Stone dust may range from 0.1 μm to more than 300 μm in diameter. On the average, 5 percent of cold aggregate feed is <74 μm (minus 200 mesh). Dust that may escape before reaching primary dust collection generally is 50 to 70 percent <74 μm. Materials emitted are given in Tables 8.1-1 and 8.1-4.

Emission factors for various materials emitted from the stack are given in Table 8.1-1. With the exception of aldehydes, the materials listed in this table are also emitted from the mixer, but mixer concentrations are 5 to 100 fold smaller than stack concentrations, lasting only during the discharge of the mixer.

TABLE 8.1-1. EMISSION FACTORS FOR SELECTED MATERIALS FROM AN ASPHALTIC CONCRETE PLANT STACK[a]

Material Emitted[b]	Emission Factor Rating	Emission Factor[c]	
		g/Mg	lb/ton
Particulate[d]	B	137	.274
Sulfur oxides (as SO_2)[d,e]	C	146S	.292S
Nitrogen oxides (as NO_2)[f]	D	18	.036
Volatile organic compounds[f]	D	14	.20
Carbon monoxide[f]	D	19	.038
Polycyclic organic material[f]	D	0.013	.000026
Aldehydes[f]	D	10	.020
Formaldehyde	D	0.077	.00015
2-Methylpropanal (isobutyraldehyde)	D	0.63	.0013
1-Butanal (n-butyraldehyde)	D	1.2	.0024
3-Methylbutanal (isovaleraldehyde)	D	8.3	.016

[a] Reference 16.

[b] Particulates, carbon monoxide, polycyclics, trace metals and hydrogen sulfide were observed in the mixer emissions at concentrations that were small relative to stack concentrations.

[c] Expressed as g/Mg and lb/ton of asphaltic concrete produced.

[d] Mean of 400 plant survey source test results.

[e] Reference 21. S = % sulfur in fuel. SO_2 may be attenuated more that 50% by adsorption on alkaline aggregate.

[f] Based on limited test data from the single asphaltic concrete plant described in Table 8.1-2.

Reference 16 reports mixer concentrations of SO_x, NO_x, VOC and ozone as less than certain values, so they may not be present at all, while particulates, carbon monoxide, polycyclics, trace metals and hydrogen sulfide were observed at concentrations that were small relative to stack amounts. Emissions from the mixer are thus best treated as fugitive.

The materials listed in Table 8.1-1 are discussed below. Factor ratings are listed for each material in the table. All emission factors are for controlled operation, based either on average industry practice shown by survey or on actual results of testing in a selected typical plant. The characteristics of this representative plant are given in Table 8.1-2.

TABLE 8.1-2. CHARACTERISTICS OF AN ASPHALTIC CONCRETE PLANT SELECTED FOR SAMPLING[a]

Parameter	Plant Sampled
Plant type	Conventional permanent batch plant
Production rate, Mg/hr (ton/hr)	160.3 ± 16% (177 ± 16%)
Mixer capacity, Mg (tons)	3.6 (4.0)
Primary collector	Cyclone
Secondary collector	Wet scrubber (venturi)
Fuel	Oil
Release agent	Fuel oil
Stack height, m (ft)	15.85 (52)

[a] Reference 16, Table 16.

The industrial survey showed that over 66 percent of operating hot mix asphalt plants use fuel oil for combustion. Possible sulfur oxide emissions from the stack were calculated assuming that all sulfur in the fuel oil is oxidized to SO_x. The amount of sulfur oxides actually released through the stack may be attenuated by water scrubbers or even by the aggregate itself, if limestone is being dried. No. 2 fuel oil has an average sulfur content of 0.22 percent.

Emission factors for nitrogen oxides, nonmethane volatile organics, carbon monoxide, polycyclic organic material and aldehydes were determined by sampling stack gas at the representative asphalt hot mix plant.

The choice of applicable control equipment ranges from dry mechanical collectors to scrubbers and fabric collectors. Attempts to apply electrostatic precipitators have met with little success. Practically all plants use primary dust collection equipment such as large diameter cyclones, skimmers or settling chambers. These chambers are often used as classifiers to return collected material to the hot aggregate elevator combine it with the dryer aggregate load. The primary collector effluent is ducted to a secondary collection device because of high emission levels if vented to the atmosphere.

TABLE 8.1-3. PARTICULATE EMISSION FACTORS FOR CONVENTIONAL HOT MIX ASPHALTIC PLANTS[a]

EMISSION FACTOR RATING: B

Type of Control	Emission Factor[b]	
	kg/Mg	lb/ton
Uncontrolled[c,d]	22.5	45.0
Precleaner[d]	7.5	15.0
High efficiency cyclone	0.85	1.7
Spray tower	0.20	0.4
Baffle spray tower	0.15	0.3
Multiple centrifugal scrubber[e]	0.035	0.07 (.007-.138)
Orifice scrubber	0.02	0.04
Venturi scrubber[f]	0.02	0.04 (.025-.053)
Baghouse[g]	0.01	0.02 (0.07-.036)

[a] References 1, 2, 5-10 and 14-16.

[b] Expressed in terms of emissions per unit weight of asphalt concrete produced.

[c] Almost all plants have at least a cleaner following the rotary dryer.

[d] Reference 16. These factors differ from those given in Table 8.1-1 because they are for uncontrolled emissions and are from an earlier survey.

[e] Reference 15. Average emission from a properly designed, installed, operated and maintained scrubber, based on a study to develop New Source Performance Standards.

[f] References 14 and 15.

[g] References 14 and 15. Emissions from a properly designed, installed, operated and maintained baghouse, based on a study to develop New Source Performance Standards.

Particulate emission factors for conventional asphaltic concrete plants are presented in Table 8.1-3. Particle size distribution information has not been included, because the particle size distribution varies with the aggregate being used, the mix being made and the type of plant operation. Potential fugitive particulate emission factors for conventional asphaltic concrete plants are shown in Table 8.1-4.

Particulate emission factors for dryer drum plants are presented in Table 8.1-5. (There are no data for other pollutants released from the dryer drum hot mix process.) Particle size distribution has not been included, because it varies with the aggregate used, the mix made and the type of plant operation. Emission factors for particulates in an uncontrolled plant can vary by a factor of 10, depending upon the percent of fine particles in the aggregate.

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1. Asphaltic Concrete Plants Atmospheric Emissions Study, EPA Contract No. 68-02-0076, Valentine, Fisher, and Tomlinson, Seattle, WA, November 1971.
2. Guide for Air Pollution Control of Hot Mix Asphalt Plants, Information Series 17, National Asphalt Pavement Association, Riverdale, MD.
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4. H.E. Friedrich, "Air Pollution Control Practices and Criteria for Hot Mix Asphalt Paving Batch Plants", JAPCA, 19(12):424-8, December 1969.
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6. G.L. Allen, et al., "Control of Metallurgical and Mineral Dust and Fumes in Los Angeles County, California", Information Circular 7627, U.S. Department of Interior, Washington, DC, April 1952.
7. P.A. Kenline, Unpublished report on control of air pollutants from chemical process industries, Robert A. Taft Engineering Center, Cincinnati, OH, May 1959.
8. G. Sallee, Private communication on particulate pollutant study between Midwest Research Institute and National Air Pollution Control Administration, Durham, NC, June 1970.

TABLE 8.1-4. POTENTIAL UNCONTROLLED FUGITIVE PARTICULATE EMISSION FACTORS FOR CONVENTIONAL ASPHALTIC CONCRETE PLANTS

EMISSION FACTOR RATING: E

Type of Operation	Particulates[a]	
	kg/Mg	lb/ton
Unloading coarse and fine aggregate to storage bins[b]	0.05	0.10
Cold and dried (and hot) aggregate elevator[b]	0.10	0.20
Screening hot aggregate[c]	0.013	0.026

[a] Expressed as units per unit weight of aggregate.
[b] Reference 18. Assumed equal to similar sources.
[c] Reference 19. Asssumed equal to similar crushed granite processes.

TABLE 8.1-5. PARTICULATE EMISSION FACTORS FOR DRYER DRUM HOT MIX ASPHALT PLANTS[a]

EMISSION FACTOR RATING: B

Type of Control	Emission Factor[b]	
	kg/Mg	lb/ton
Uncontrolled	2.45	4.9
Cyclone or multicyclone	0.34	0.67
Low energy wet scrubber[c]	0.04	0.07
Venturi scrubber	0.02	0.04

[a] Reference 11.
[b] Expressed in terms of emissions per unit weight of asphalt concrete produced. These factors differ from those for conventional asphaltic concrete plants because the aggregate contacts, and is coated with, asphalt early in the dryer drum process.
[c] Either stack sprays where water droplets are injected into the exit stack, or a dynamic scrubber that incorporates a wet fan.

9. J.A. Danielson, Unpublished test data from asphalt batching plants, Los Angeles County Air Pollution Control District, Presented at Air Pollution Control Institute, University of Southern California, Los Angeles, CA, November 1966.

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11. Preliminary Evaluation of Air Pollution Aspects of the Drum Mix Process, EPA-340/1-77-004, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1976.

12. R.W. Beaty and B.M. Bunnell, "The Manufacture of Asphalt Concrete Mixtures in the Dryer Drum", Presented at the Annual Meeting of the Canadian Technical Asphalt Association, Quebec City, Quebec, November 19-21, 1973.

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18. Evaluation of Fugitive Dust from Mining, EPA Contract No. 68-02-1321, Pedco Environmental Specialists, Inc., Cincinnati, OH, June 1976.

19. J.A. Peters and P.K. Chalekode, "Assessment of Open Sources", Presented at the Third National Conference on Energy and the Environment, College Corner, OH, October 1, 1975.

20. Illustration of Dryer Drum Hot Mix Asphalt Plant, Pacific Environmental Services, Inc., Santa Monica, CA, 1978.

21. Herman H. Forsten, "Applications of Fabric Filters to Asphalt Plants", Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, TX, June 1978.

22. Emission of Volatile Organic Compounds from Drum Mix Asphalt Plants, EPA Contract No. 68-01-2585, JACA Corporation, Fort Washington, PA, September 1980.

8.2 ASPHALT ROOFING

8.2.1 General[1]

The asphalt roofing industry manufactures asphalt saturated felt rolls, shingles, roll roofing with mineral granules on the surface, and smooth roll roofing that may contain a small amount of mineral dust or mica on the surface. Most of these products are used in roof construction, with small quantities used in walls and other building applications.

8.2.2 Process Description

The manufacturing of asphalt felt, roofing, and shingles involves the saturating and coating of felt with heated asphalt (saturant asphalt and/or coating asphalt) by means of dipping and/or spraying. The process can be divided into (1) asphalt storage, (2) asphalt blowing, (3) felt saturation, (4) coating and (5) mineral surfacing. Glass fiber is sometimes used in place of the paper felt, in which case the asphalt saturation step is bypassed.

Preparation of the asphalt is an integral part of the production of asphalt roofing. This preparation, called "blowing", involves the oxidation of asphalt flux by bubbling air through liquid asphalt flux at 260°C (500°F) for 1 to 4.5 hours, depending on the desired characteristics of the asphalt, such as softening point and penetration rate.[2] A typical plant will blow from four to six batches per 16 hour day, and the roofing line will operate for 16 hours per day and 5 days per week. Blowing may be done either in vertical tanks or in horizontal chambers. Inorganic salts such as ferric chloride ($FeCl_3$) may be used as catalysts to achieve desired properties and to increase the rate of reaction in the blowing still, thus decreasing the time required for each blow.[3] Air blowing of asphalt may be conducted at oil refineries, asphalt processing plants, and asphalt roofing plants. Figure 8.2-1 illustrates an asphalt blowing operation.

Figure 8.2-2 shows a typical line for the manufacture of asphalt-saturated felt, which consists of a paper feed roll, a dry looper section, a saturator spray section (if used), a saturator dipping section, steam-heated drying-in drums, a wet looper, water cooled rollers, a finish floating looper, and a roll winder.

Organic felt may weigh from 25 to 55 pounds per 480 square feet (a common unit in the paper industry), depending upon the intended product. The felt is unrolled from the unwind stand into the dry looper, which maintains a constant tension on the material. From the dry looper, the felt may pass into the spray section of the saturator (not used in all plants), where asphalt at 205° to 250°C (400° to 480°F) is sprayed onto one side of the felt through several nozzles. In the saturator dip section, the saturated felt is drawn over a series of rollers, with the bottom rollers submerged in hot asphalt at 205° to 250°C (400° to 480°F).

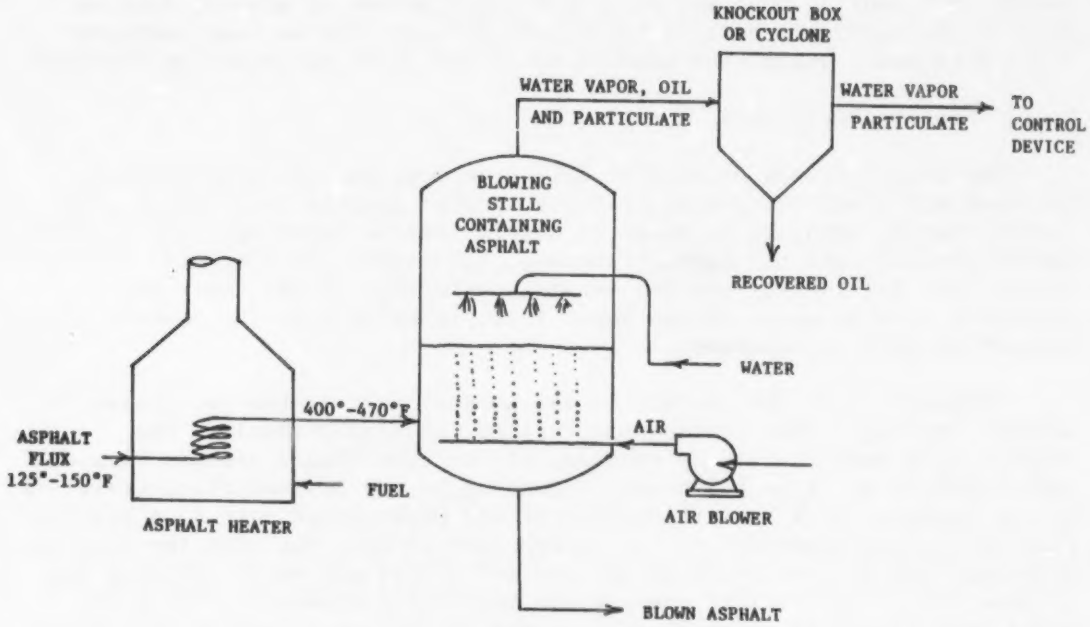
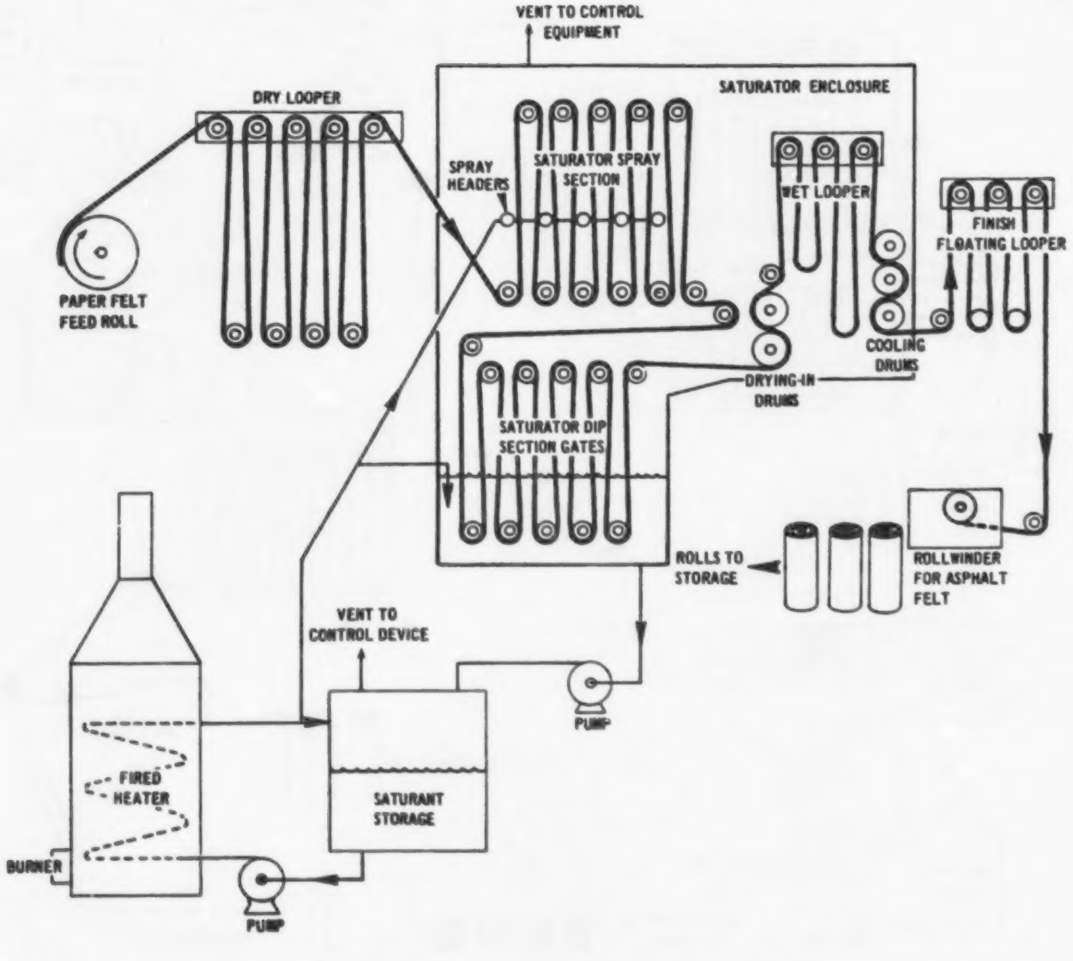

KNOCKOUT BOX
OR CYCLONE
WATER VAPOR, OIL
AND PARTICULATE
WATER VAPOR
PARTICULATE
TO
CONTROL
DEVICE
BLOWING
STILL
CONTAINING
ASPHALT
RECOVERED OIL
WATER
400°-470°F
AIR
ASPHALT
FLUX
125°-150°F
FUEL
AIR BLOWER
ASPHALT HEATER
BLOWN ASPHALT

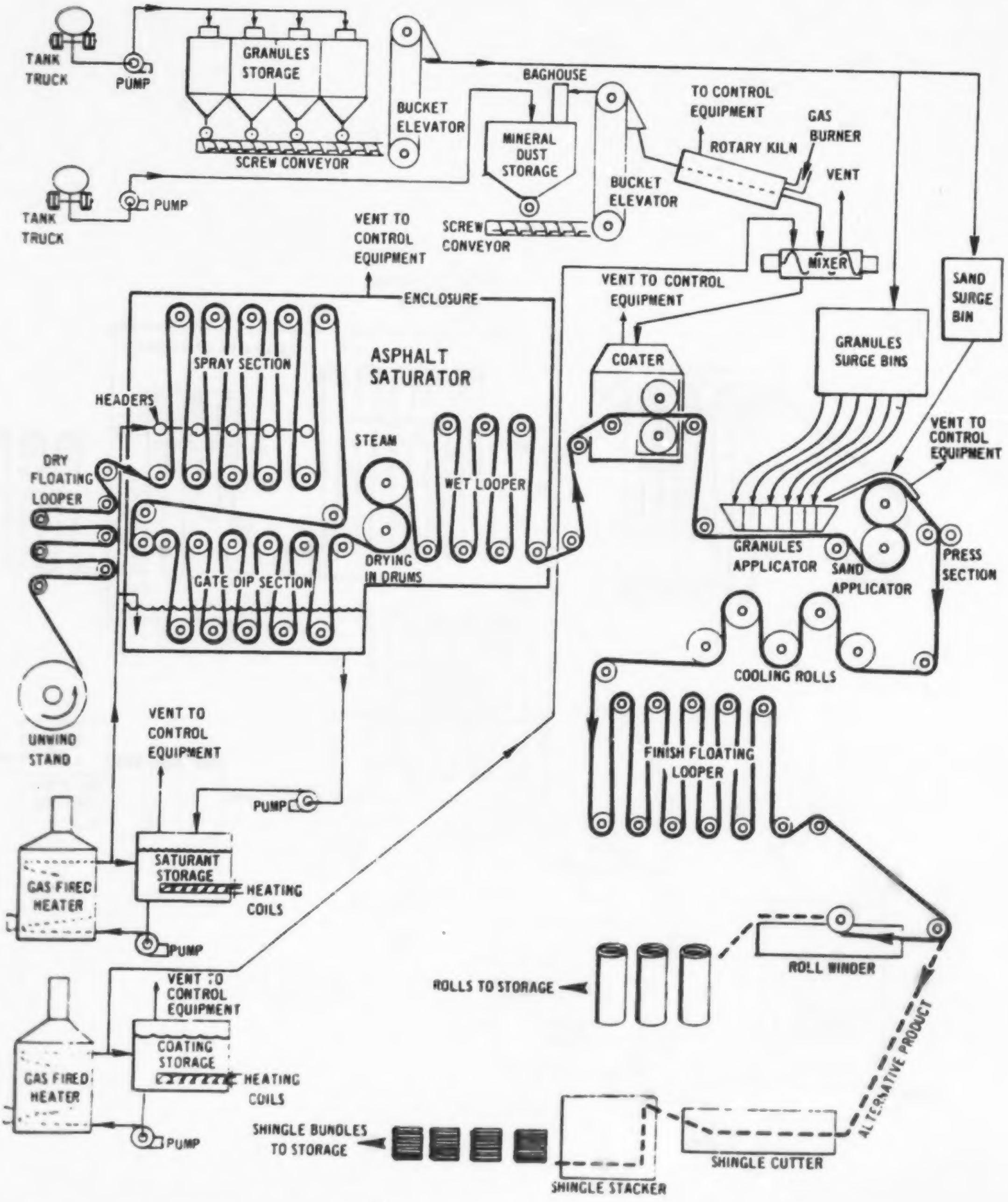
Figure 8.2.-1. Air blowing of asphalt.[3]

At the next step, steam heated drying-in drums and the wet looper provide the heat and time, respectively, for the asphalt to penetrate the felt. The saturated felt then passes through water cooled rolls and onto the finish floating looper, and then is rolled and cut on the roll winder to product size. Two common weights of asphalt felt are 15 and 30 pounds per 108 square feet (108 square feet of felt covers exactly 100 square feet of roof).

A typical process for manufacturing asphalt shingles, mineral surfaced rolls and smooth rolls is illustrated in Figure 8.2-3. This line is similar to the felt line, except that following the wet looper are a coater, a granule applicator, a press section, water cooled rollers, a finish floating looper, and either a roll winder or a shingle cutter and stacker. After leaving the wet looper, the saturated felt passes through the coater. Filled asphalt coating at 180° to 205°C (355° to 400°F) is released through a valve onto the felt just as it passes into the coater.[1] Filled asphalt is prepared by mixing coating asphalt at 205°C (400°F) and


VENT TO CONTROL EQUIPMENT
SATURATOR ENCLOSURE
DRY LOOPER
SPRAY HEADERS
SATURATOR SPRAY SECTION
WET LOOPER
FINISH FLOATING LOOPER
PAPER FELT FEED ROLL
COOLING DRUMS
DRYING-IN DRUMS
SATURATOR DIP SECTION GATES
ROLLS TO STORAGE
ROLLWINDER FOR ASPHALT FELT
VENT TO CONTROL DEVICE
PUMP
FIRED HEATER
SATURANT STORAGE
BURNER
PUMP

8.2-2. Schematic of line for manufacturing asphalt saturated felt.[1]


TANK TRUCK
PUMP
GRANULES STORAGE
SCREW CONVEYOR
BUCKET ELEVATOR
BAGHOUSE
MINERAL DUST STORAGE
TO CONTROL EQUIPMENT
GAS BURNER
ROTARY KILN
VENT
BUCKET ELEVATOR
TANK TRUCK
PUMP
VENT TO CONTROL EQUIPMENT
SCREW CONVEYOR
MIXER
VENT TO CONTROL EQUIPMENT
SAND SURGE BIN
ENCLOSURE
ASPHALT SATURATOR
SPRAY SECTION
HEADERS
COATER
GRANULES SURGE BINS
STEAM
WET LOOPER
DRY FLOATING LOOPER
VENT TO CONTROL EQUIPMENT
DRYING IN DRUMS
GATE DIP SECTION
GRANULES APPLICATOR
SAND APPLICATOR
PRESS SECTION
COOLING ROLLS
UNWIND STAND
VENT TO CONTROL EQUIPMENT
FINISH FLOATING LOOPER
PUMP
SATURANT STORAGE
HEATING COILS
GAS FIRED HEATER
PUMP
ROLLS TO STORAGE
ROLL WINDER
VENT TO CONTROL EQUIPMENT
COATING STORAGE
HEATING COILS
GAS FIRED HEATER
PUMP
ALTERNATIVE PRODUCT
SHINGLE BUNDLES TO STORAGE
SHINGLE STACKER
SHINGLE CUTTER

8.2-3. Schematic of line for manufacturing asphalt shingles, mineral surfaced rolls, and smooth rolls.[1]

a mineral stabilizer (filler) in approximately equal proportions. The filled asphalt is pumped to the coater. Sometimes the mineral stabilizer is dried at about 120°C (250°F) in a dryer before mixing with the coating asphalt. Heated squeeze rollers in the coater distribute the coating evenly upon the felt surface, to form a thick base coating to which rock granules, sand, talc, or mica can adhere. After leaving the coater, a felt to be made into shingles or mineral surfaced rolls passes through the granules applicator where granules are fed onto the hot, coated surface. The granules are pressed into the coating as it passes through squeeze rollers. Sand, talc or mica is applied to the back, or opposite, side of the felt and is also pressed into the felt surface. Following the application of the granules, the felt is cooled rapidly and is transferred through the finish flowing looper to a roll winder or shingle cutter.

8.2.3 Emissions and Controls

The atmospheric emissions from asphalt roofing manufacturing are:

1. gaseous and particulate organic compounds that include small amounts of particulate polycyclic organic matter (PPOM),

2. emissions of small amounts of aldehydes, carbon monoxide and sulfur dioxide, and

3. particulate emissions from mineral handling and storage.

The sources of the above pollutants are the asphalt blowing stills, the saturator and coater, the asphalt storage tanks, and the mineral handling and storage facilities. Emission factors from uncontrolled blowing and saturating processes for particulate, carbon monoxide, and volatile organic carbon as methane and nonmethane are summarized in Table 8.2-1.

A common method to control emissions at asphalt roofing plants is completely to enclose the saturator, wet looper and coater and then to vent the emissions to one or more control devices (see Figures 8.2-2 and 8.2-3). Fugitive emissions from the saturator may pass through roof vents and other openings in the building, if the saturator enclosure is not properly installed and maintained. Control devices used in the industry include afterburners, high velocity air filters, low voltage electrostatic precipitators, and wet scrubbers. Blowing operations are controlled by afterburners. Table 8.2-2 presents emission factors for controlled blowing and saturating processes.

Particulate emissions associated with mineral handling and storage operations are captured by enclosures, hoods or pickup pipes and are controlled by using cyclones and/or fabric filters with removal efficiencies of approximately 80-99 percent.

TABLE 8.2-1. EMISSION FACTORS FOR ASPHALT ROOFING MANUFACTURING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: PARTICULATE- A
OTHER- D

	Particulates		Carbon monoxide		Volatile organic compounds			
					methane		nonmethane	
Operation	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Asphalt blowing[b]								
Saturant[c]	3.6	7.2	0.14[d]	0.27[d]	e	e	e	e
Coating[f]	13.4	26.7			0.94	1.88	0.93	1.86
Shingle saturation[g]	0.25	0.50	0.01	0.02	0.04	0.08	0.01	0.02
Shingle saturation[h]	1.57	3.14	0.13	0.25	0.11	0.22	0.02	0.03

[a] References 2 and 4.
[b] Expressed as kg/Mg (lb/ton) of asphalt processed.
[c] Saturant blow of 1.5 hours.
[d] Reference 2. CO data for uncontrolled emissions from stills was not obtained during latest test program.
[e] Species data not available for saturant blow. Total organics (as CH_4) for saturant blow are 0.73 kg/Mg (1.460 lb/ton).
[f] Coating blow of 4.5 hours.
[g] Expressed as kg/Mg (lb/ton) of 106.5 kg (235 lb) shingle produced. Data from dip saturators.
[h] Data from spray/dip saturator.

NOTES: -Particulate polycyclic organic matter is about 0.3 % of particulate for blowing stills and 0.1 % of particulate for saturators.

-Aldehyde emission measurements made during coating blows: 4.6×10^{-5} kg/Mg (9.2×10^{-5} lb/ton).

-Aldehyde emissions data taken from one saturator only, with afterburner the control device: 0.004 kg/Mg (0.007 lb/ton).

-Species data not obtained for uncontrolled VOC, assumed same percentage methane/nonmethane as in controlled emissions.

TABLE 8.2-2. EMISSION FACTORS FOR ASPHALT ROOFING MANUFACTURING WITH CONTROLS[a]

EMISSION FACTOR RATING: PARTICULATE- A
OTHER- D

	Particulates		Carbon monoxide		Volatile organic compounds			
					methane		nonmethane	
Operation	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Asphalt blowing[b]								
Saturant[c]	0.25	0.50	0.6	1.2	d	d	d	d
Coating[e]	0.45	0.89	4.4	8.8	0.05	0.10	0.05	0.09
Shingle saturation[f]	0.03	0.06	0.45	0.89[g]	0.08	0.15	0.01	0.02

[a] References 2 and 4.
[b] Expressed as kg/Mg (lb/ton) of asphalt processed.
[c] Saturant blow of 1.5 hours.
[d] Species data not available for saturant blow. Total organics (as CH_4) for saturant blow are 0.015 kg/Mg (0.03 lb/ton).
[e] Coating blow of 4.5 hours.
[f] Expressed as kg/Mg (lb/ton) of 106.5 kg (235 lb) shingle produced (averages of test data from four plants).
[g] CO emissions data taken from one plant only, with afterburner the control device. Temperature of afterburner not high enough to convert CO to CO_2.

NOTE: Particulate polyclic organic matter is about 0.03 % of particulate for blowing stills and about 1.1 % of particulate for saturators.

In this industry, closed silos are used for mineral storage, so open storage piles are not a problem. To protect the minerals from moisture pickup, all conveyors that are outside the buildings are enclosed. Fugitive mineral emissions may occur at the unloading point, depending on the type of equipment used. The discharge from the conveyor to the silos is controlled by either a cyclone or a fabric filter.

References for Section 8.2

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APPENDIX C

NEDS SOURCE CLASSIFICATION CODES

and

EMISSION FACTOR LISTING

Source Classification Codes (SCC), defined for use in the National Emissions Data System (NEDS), represent individual processes or functions logically associated with points of air pollutant emissions. Related to each SCC are emission factors for the five NEDS pollutants (particulates, sulfur oxides, nitrogen oxides, hydrocarbons and carbon monoxide). These emission factors are used in the calculation of emissions estimates in NEDS and, normally, are the same as the emission factors appearing in AP-42.

Updated editions of the NEDS SCC and emission factor listing appear in AEROS Volume V. Because of its availability, the listing will no longer be carried in AP-42. The SCC listing that appeared in Supplement 9 of AP-42 does not reflect changes and additions made to the NEDS SCC file since then.

Individuals who wish to obtain copies of the most current NEDS SCC listing may request the most recent version of AEROS Volume V from:

Requests and Information Section
National Air Data Branch (MD-14)
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Phone (919) 541-5694, (FTS) 629-5694

APPENDIX E

COMPILATION OF LEAD EMISSION FACTORS

INTRODUCTION

Lead was not involved as a specific pollutant in the earlier editions and supplements of AP-42. Since a National Ambient Air Quality Standard for lead has been issued, it has become necessary to determine emission factors for lead, and these are given in Table E-1. The AP-42 Section number given in this table for each process corresponds to the pertinant section in the body of the document.

Lead emission factors for combustion and evaporation from mobile sources require a totally different treatment, and they are not included in this Appendix.

Table E-1. UNCONTROLLED LEAD EMISSION FACTORS

AP-42 Section	Process	Emission factor[a,b]		References
		Metric	English	
1.1	Bituminous coal combustion (all furnace types)	0.8 (L) kg/10^6 kg (Average L = 8.3 ppm)	1.6 (L) lb/10^3 ton	1,4-6
1.2	Anthracite coal combustion (all furnace types)	0.8 (L) kg/10^6 kg (Average L = 8.1 ppm)	1.6 (L) lb/10^3 ton	1,4-6
1.3	Residual fuel oil combustion (all boiler types)	0.5 (L) kg/$10^3$$m^3$ (Average L = 1.0 ppm)	4.2 (L) lb/10^6 gal	1,7
1.3	Distillate fuel oil combustion (all boiler types)	0.5 (L) kg/$10^3$$m^3$ (Average L = 0.1 ppm)	4.2 (L) lb/10^6 gal	1,7
1.7	Lignite combustion (all boiler types)	5-6 kg/10^6 kg	10-11 lb/10^3 tons	2
1.11	Waste oil combustion	9 (P) kg/m^3 (Average P - 1.0 percent)	75 (P) lb/10^3 gal	18,51,52
2.1	Refuse incineration (municipal incinerator)	0.2 kg/MT chgd	0.4 lb/ton chgd	1,3,9-11
2.5	Sewage sludge incineration (wet scrubber controlled)			
	Multiple hearth	.01-.02 kg/MT chgd	.02-.03 lb/ton chgd	3,12
	Fluidized bed	.0005-.002 kg/MT chgd	.001-.003 lb/ton	3,12

Table E-1 (continued). UNCONTROLLED LEAD EMISSION FACTORS

AP-42 Section	Process	Emission factor[a,b] Metric	Emission factor[a,b] English	References
5.22	Lead alkyl production			
	Electrolytic process	0.5 kg/MT prod	1.0 lb/ton prod	1,3,53
	Sodium-lead alloy process			
	Recovery furnace	28 kg/MT prod	55 lb/ton prod	1,53,54
	Process vents, TEL	2 kg/MT rpod	4 lb/ton prod	1
	Process vents, TML	75 kg/MT prod	150 lb/ton prod	1
	Sludge pits	0.6 kg/MT prod	1.2 lb/ton prod	1
7.2	Metallurgical coke manufacturing	.00018 kg/MT coal chgd	.00035 lb/ton coal chgd	1,13,14
7.3	Primary copper smelting			
	Roasting	0.03 kg/MT conc	0.05 lb/ton conc	65
	Smelting (reverberatory furnace)	0.03 kg/MT conc	0.06 lb/ton conc	65
	Converting	0.06 kg/MT conc	0.12 lb/ton conc	65
7.4	Ferroalloy production - electric arc furnace (open)			
	Ferrosilicon (50%); FeSi	0.15 kg/MT prod	0.29 lb/ton prod	20
	Silicon metal	0.0015 kg/MT prod	0.0031 lb/ton prod	1,19
	Silico-manganese	0.29 kg/MT prod	0.57 lb/ton prod	1,21
	Ferro-manganese (standard)	0.06 kg/MT prod	0.11 lb/ton prod	1,3
	Ferrochrome-silicon	0.04 kg/MT prod	0.08 lb/ton prod	20
	High carbon ferrochrome	0.17 kg/MT prod	0.34 lb/ton prod	20
7.4	Ferroalloy production - blast furnace	1.9 kg/MT prod	3.7 lb/ton prod	1,3
7.5	Iron and steel production			
	Sintering (windbox + vent discharges)	0.0067 kg/MT sinter	0.013 lb/ton sinter	1,23,24
	Blast furnace (for mixed charge)	0.062 kg/MT Fe	0.124 lb/ton Fe	1,23

Table E-1 (continued). UNCONTROLLED LEAD EMISSION FACTORS

AP-42 Section	Process	Emission factor[a,b]		References
		Metric	English	
	Open hearth			
	Lancing	0.07 kg/MT steel	0.14 lb/ton steel	1
	No lancing	0.035 kg/MT steel	0.07 lb/ton steel	1
	Basic oxygen furnace (BOF)	0.1 kg/MT steel	0.2 lb/ton steel	1,23,25
	Electric arc furnace			
	Lancing	0.11 kg/MT steel	0.22 lb/ton steel	1,28
	No lancing	0.09 kg/MT steel	0.18 lb/ton steel	1
7.6	Primary lead smelting			
	Ore crushing and grinding	0.15 kg/MT ore	0.3 lb/ton ore	29
	Sintering	4.2-170 kg/MT Pb prod	8.4-340 lb/ton Pb prod	1,21,22, 30-33
	Blast furnace	8.7-50 kg/MT Pb prod	17.5-100 lb/ton Pb prod	1,30,32, 33,35,36
	Dross reverberatory furnace	1.3-3.5 kg/MT Pb prod	2.6-7.0 lb/ton Pb prod	1,18,30, 34,36
7.7	Zinc smelting			
	Ore unloading, storage, transfer	0.035-0.1 kg/MT ore	0.07-0.2 lb/ton ore	1
	Sintering	13.5-25 kg/MT ore	27-50 lb/ton ore	1,30,38
	Horizontal retorts	1.2 kg/MT ore	2.4 lb/ton ore	1,30,38
	Vertical retorts	2-2.5 kg/MT ore	4-5 lb/ton ore	1,30,38
7.9	Secondary copper smelting and alloying			
	Reverberatory furnace (high lead alloy 58% Pb)	25 kg/MT prod	50 lb/ton prod	1,26,39-41
	Red and yellow brass (15% Pb)	6.6 kg/MT prod	13.2 lb/ton prod	1,26,39-41
	Other alloys (7% Pb)	2.5 kg/MT prod	5 lb/ton prod	1,26,39-41
7.10	Gray iron foundries			
	Cupola	0.05-0.6 kg/MT prod	0.1-1.1 lb/ton prod	1,3,26, 42,43

Table E-1 (continued). UNCONTROLLED LEAD EMISSION FACTORS

AP-42 Section	Process	Emission factor[a,b]		References
		Metric	English	
	Reverberatory furnace	0.006-0.7 kg/MT prod	0.012-0.14 lb/ton prod	1
	Electric induction furnace	0.005-.05 kg/MT prod	0.009-0.1 lb/ton prod	1
7.11	Secondary lead smelting			
	Reverberatory furnace	17 kg/MT Pb prod	34 lb/ton Pb prod	1,66
	Blast cupola furnace	22 kg/MT Pb prod	44 lb/ton Pb prod	1,66
	Refining kettles	0.1 kg/MT Pb prod	0.21 lb/ton Pb prod	46
7.15	Storage battery production (total)	8 kg/10^3 batteries	17.7 lb/10^3 batteries	1,55-58
	Grid casting	0.4 kg/10^3 batteries	0.9 lb/10^3 batteries	1,55-58
	Lead oxide mill (baghouse outlet)	0.05 kg/10^3 batteries	0.12 lb/10^3 batteries	1,55-58
	Three-process operations[c]	6.6 kg/10^3 batteries	14.6 lb/10^3 batteries	1,55-58
	Lead reclaim furnace	0.35 kg/10^3 batteries	0.77 lb/10^3 batteries	1,55-58
	Small parts casting	0.05 kg/10^3 batteries	0.10 lb/10^3 batteries	1,55-58
7.16	Lead oxide and pigment production			
	Barton pot (baghouse outlet)	0.22 kg/MT prod	0.44 lb/ton prod	1,61,62
	Calcining furnace	7 kg/MT prod	14 lb/ton prod	61
	Red lead (baghouse outlet)	0.5 kg/MT prod	0.9 lb/ton prod	1,54
	White lead (baghouse outlet)	0.28 kg/MT prod	0.55 lb/ton prod	1.54
	Chrome pigments	0.065 kg/MT prod	0.13 lb/ton prod	1.54
7.17	Miscellaneous lead products			
	Type metal production	0.13 kg/MT Pb proc	0.25 lb/ton Pb Proc	1,63
	Can soldering[d]	160 kg/10^6 baseboxes prod	0.18 ton/10^6 baseboxes prod	1
	Cable covering	0.25 kg/MT proc	0.5 lb/ton Pb proc	1,3,64

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